Delaware Department of Natural Resources
and Environmental Control

AMENDMENT TO THE WASTE LOAD ALLOCATION (WLA) OF THE 2005 MURDERKILL RIVER WATERSHED TMDLs

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PREFACE

As required by the Federal Clean Water Act, the Delaware Department of Natural Resources and Environmental Control (DNREC) is responsible for implementing water quality monitoring and assessment activities in the State and also for establishing Total Maximum Daily Loads (TMDLs) on impaired State surface waters as indicated on the State's 303(d) List.

On May 12, 2005, the Cabinet Secretary of DNREC issued Order No. 2005-W-0025 adopting amended Total Maximum Daily Load (TMDL) Regulations for nutrients and oxygen consuming compounds for the entire Murderkill River Watershed. Since promulgation of the 2005 amended TMDL, a multi-year monitoring, research and modeling study of the Murderkill River Watershed by DNREC and other cooperating agencies and institutions resulted in proposing scientifically-based, site-specific dissolved oxygen (DO) and nutrient criteria for the tidal Murderkill River. This multi-year effort resulted in an amendment to the WLA component of the 2005 TMDL that will comply with the proposed site-specific DO and nutrient criteria for tidal Murderkill River.

This proposed amendment to the WLA component of the 2005 Murderkill River Watershed TMDL will be presented during a Public Hearing to be held on January 22, 2014 at the DNREC main office in Dover. All comments received before and during the Public Hearing process will be considered by DNREC. Based on the comments received, the report may be modified accordingly.

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SECTION 1

INTRODUCTION

The Murderkill River watershed is situated in the southeastern portion of Kent County in Delaware and includes several main tributaries (Double Run, Spring Creek, Browns Branch) and five lakes/ponds (McGinnis Pond, Andrews Lake, Killen Pond, Coursey Pond, McColley Pond). The river has tidal reaches from its mouth at Bowers Beach upstream to locations just downstream from the pond/lake dams and near Barratts Chapel Road on Double Run. At Bowers Beach, the Murderkill River connects to Delaware Bay. The river is bounded by the St. Jones River watershed to the north and the Mispillion River watershed to the south. There are large tidal marshes interfacing with the river from Bowers Beach upstream to near Route 1. Figure 1 presents a study area map of the Murderkill River watershed.

Historical water quality monitoring conducted by the Delaware Department of Natural Resources and Environmental Control (DNREC) has shown that waters in the tidal portions of the Murderkill River do not meet their designated uses because of low dissolved oxygen (DO) levels that are below the State water quality standards of 5 mg/L as a daily average and 4 mg/L as an instantaneous minimum. Based on these DO violations, DNREC listed the tidal segments of the Murderkill River on the State's 1996 303(d) list of impaired waters that required the development of a Total Maximum Daily Load (TMDL) to bring the river into compliance with State water quality standards. In 2001, DNREC completed development of a water quality model of the Murderkill River and used it to propose TMDLs for sources of oxygen consuming compounds and nutrients in the watershed. This 2001 TMDL was later amended by DNREC in 2005 (DNREC, 2005).

Since promulgation of the 2005 TMDL, significant additional monitoring, modeling and related studies have been completed (HDR|HydroQual, 2013a) that have advanced the science and understanding of the water quality dynamics in the river. This effort has been coordinated through the activities of the Murderkill Study Group through the leadership of DNREC and the Kent County Department of Public Works (KCDPW). Members of this Study Group that have been involved in the new research and development include: DNREC; KCDPW; University of Delaware; United States Geological Survey (USGS); Delaware Geological Survey (DGS); University of Maryland; Stroud Water Research Center; Academy of Natural Science; and HDR|HydroQual. The purpose of these additional efforts was to establish site-specific water quality standards for DO and nutrients for the tidal portion of the Murderkill River and to amend the 2005 TMDL for the tidal Murderkill River, if necessary. The TMDL and associated allocations for the upstream watershed areas will remain the same as determined in the amended 2005 TMDL.

To assist with this process, HDR|HydroQual developed mathematical models of the Murderkill River watershed. These mathematical models included a landside watershed model to calculate runoff quantity and nonpoint source (NPS) loads, a hydrodynamic model to calculate the movement of water in the tidal reaches of the Murderkill River, and a water quality model with a sediment flux sub-model that is coupled to the hydrodynamic model to calculate water quality in the tidal reaches of the river. DNREC used the above modeling tools, along with findings from other monitoring and research studies, to propose site-specific nutrient and DO criteria for the tidal Murderkill River that reflect the natural processes associated with the extensive tidal marshes that affect DO levels in the tidal river. These research studies, data collection/analysis and model development are presented in the following reports and journal articles:

- Murderkill River Watershed TMDL Model Development and Calibration (HDR|HydroQual, 2013a);
- Tidal Murderkill River Site-Specific Nutrient and Dissolved Oxygen Criteria (HDR|HydroQual, 2013b);
- Primary Production in the Murderkill River. A Report to Kent County and DNREC by the School of Marine Science and Policy, College of Earth, Ocean, and Environment, University of Delaware, Lewes DE (Sharp, J.H., 2011);
- Temporal and Spatial Variability of Sea Level and Volume Flux in the Murderkill Estuary (Wong, K-C., B. Dzwonkowski and W.J. Ullman, 2009. Estuarine, Coastal and Shelf Science, 84 (2009) 440-446);
- Water Level and Velocity Characteristics of a Salt Marsh Channel in the Murderkill Estuary, Delaware (Dzwonkowski, B., K-C. Wong and W.J. Ullman, 2013. Journal of Coastal Research, in press);
- Nutrient Exchange between a Salt Marsh and the Murderkill Estuary, Kent County, Delaware (Ullman, W., A. Aufdenkampe, R.L. Hays and S. Dix, 2013);
- Nutrient Flux Study Results from the Murderkill River-Marsh Ecosystem, Final Report. Prepared for Kent County Levy Court (Chesapeake Biogeochemical Associates, 2010);
- Characterization of Tidal Wetland Inundation in the Murderkill River Estuary. Delaware Geological Survey, University of Delaware. Submitted to Kent County Levy Court (McKenna, T.E., 2013); and
- Vertical Profiles of Radioisotopes, Nutrients and Diatoms in Sediment Cores from the Tidal Murderkill River Basin: A Historical Analysis of Ecological Change and Sediment Accretion. PCER Report No. 10-01. Patrick Center for Environmental Research, The Academy of Natural Sciences (Velinsky, D., C. Sommerfield and D. Charles, 2010).

In addition, continuous tidal monitoring for salinity, temperature, DO, pH, water elevation and volume flux was completed by the USGS in the tidal Murderkill River near Frederica and at Bowers Beach along with the installation of three stream gaging stations to monitor flow in the watershed on the Murderkill River, Pratt Branch and Browns Branch. Increased sampling in the Murderkill River watershed by DNREC was also completed for this study along with the completion of long-term BOD studies on river samples and Kent County Regional Wastewater Treatment Facility (KCRWTF) effluent. The DNREC sampling frequency was increased to bi-weekly or monthly with the addition of a few additional monitoring locations.

A summary of some of the data and modeling information related to the Murderkill River Watershed TMDL is presented in the following sections but detailed information relating to the research studies, data collection and modeling are contained in the above references.

1.1 303(D) LISTED WATERBODIES

The water bodies listed on the State of Delaware's 2012 303(d) List for nutrient and DO impairments in the Murderkill River Watershed are presented in Table 1 (DNREC, 2013). There are a total of 12 listed water segments: 3 tidal segments of the Murderkill River (lower Murderkill, Spring Creek, mid Murderkill); 4 freshwater stream segments (Browns Branch, upper Murderkill, Fan Branch, Black Swamp Creek); and 5 freshwater lakes or ponds (McGinnis Pond, Andrews Lake, Coursey Pond, Killens Pond, McCauley Pond). These segments are listed for nutrients, ammonia and/or DO with the most probable source of pollutants identified as point source (PS) and nonpoint source (NPS). The TMDL development in the Murderkill River watershed and presented in this report was completed to address the nutrient and DO impairments in the tidal Murderkill River (DE 220-001).

1.2 DESIGNATED USES

According to the "State of Delaware Surface Water Quality Standards (Amended July 11, 2004)", the designated uses applicable to the Murderkill River that must be maintained and protected through the application of appropriate criteria are uses for: industrial water supply; primary contact recreation; secondary contact recreation; fish, aquatic life and wildlife including shellfish propagation; and agricultural water supply in freshwater segments only (DNREC, 2011). These designated uses are applicable to the Murderkill River and are achieved and maintained through the application of water quality standards and criteria as outlined in the next section.

Table 1. Murderkill River Watershed Nutrient and DO TMDL Segments					
Water Body ID	**Segment (Category)**	**Size Affected**	**Description**	**Parameters**	**Probable Source**
DE 220-001	Lower Murderkill (4A)	7.6 miles	From the confluence with Spring Creek to the mouth at Delaware Bay	Nutrients, DO	PS, NPS
DE 220-002	Spring Creek (5)	15.8 miles	From the headwaters to the confluence with Murderkill River, excluding Andrews Lake and McGinnis Pond	Nutrients, DO	PS, NPS
DE 220-003	Mid Murderkill River (5)	9.2 miles	From McCauley and Coursey Pond to the confluence with Spring Creek	Nutrients	PS, NPS
DE 220-004	Browns Branch (5)	8.8 miles	From the headwaters adjacent to Harrington to the confluence with McCauley Pond	Nutrients, DO Ammonia	NPS PS, NPS
DE 220-005	Upper Murderkill River (5)	7.4 miles	From the headwaters to the confluence with Coursey Pond, excluding Killens and Coursey Ponds	Nutrients, DO	NPS
DE 220-005	Upper Murderkill River (5)	2.31 miles	Fan Branch - from the headwaters to the confluence with Murderkill River	DO	NPS
DE 220-005	Upper Murderkill River (5)	0.75 miles	Black Swamp Creek - from the headwaters of Black Swamp to the confluence with the next larger stream	DO	NPS
DE 220-L01	McGinnis Pond (4A)	31.3 acres	Pond east of Viola	Nutrients, DO	NPS
DE 220-L02	Andrews Lake (4A)	17.5 acres	Pond west of Frederica	Nutrients	NPS
DE 220-L03	Coursey Pond (4A)	58.1 acres	Pond southwest of Frederica	Nutrients	NPS
DE 220-L04	Killens Pond (4A)	75.1 acres	Pond southwest of Felton	Nutrients	NPS
DE 220-L05	McCauley Pond (4A)	49.0 acres	Pond northeast of Harrington	Nutrients	NPS

1.3 EXISTING WATER QUALITY STANDARDS AND NUTRIENT TARGETS

According to the "State of Delaware Surface Water Quality Standards (Amended June 1, 2011)", water quality standards (WQS) for dissolved oxygen (DO) exist. The existing DO WQSs in freshwater are a daily average of not less than 5.5 mg/L (minimum of 4 mg/L) and in marine waters are a daily average of not less than 5 mg/L (minimum of 4 mg/L).

For nutrients, some site-specific or basin-specific standards exist but acceptable nutrient levels are determined based on their ultimate effect on DO or algal levels through nutrient-algal-DO relationships (eutrophication) and/or threshold levels. The nutrient standards are currently in narrative form for controlling nutrient over enrichment and are stated as:

> "Nutrient over enrichment is recognized as a significant problem in some surface waters of the State. It shall be the policy of this Department to minimize nutrient input to surface waters from point sources and human induced nonpoint sources. The types of, and need for, nutrient controls shall be established on a site-specific basis. For lakes and ponds, controls shall be designed to eliminate over enrichment."

Although national numeric nutrient criteria have not been established, DNREC has used target levels of 2.0-3.0 mg/L for total nitrogen (TN) and 0.1-0.2 mg/L for total phosphorous (TP) for listing water bodies on the State's 303(d) listings and 305(b) assessment reports. Nutrient related algal effects typically require sufficient time for impacts to be noticed (i.e., impacts are long term in nature rather than instantaneous), therefore, the nutrient targets are applied on a long-term average basis (i.e., generally annual average).

1.4 SITE-SPECIFIC DISSOLVED OXYGEN AND NUTRIENT CRITERIA

Since the development of the original Murderkill River Watershed TMDL in 2001 and the TMDL Amendment in 2005, significant additional monitoring, modeling and related studies have been completed (HDR|HydroQual, 2013a) that have advanced the science and understanding of the water quality dynamics in the river. This effort has been coordinated through the activities of the Murderkill Study Group through the leadership of DNREC and the Kent County Department of Public Works (KCDPW). The purpose of these additional efforts was to establish site-specific water quality standards for DO and nutrients for the tidal portion of the Murderkill River and amend the 2005 TMDL for the tidal Murderkill River, if necessary. The development of and resulting site-specific DO and nutrient criteria developed for the tidal Murderkill River are presented in the report titled *"Tidal Murderkill River Site-Specific Nutrient and Dissolved Oxygen Criteria"* (HDR|HydroQual, 2013b). These site-specific criteria, which will be the subject of a Public Hearing on January 22, 2014, are used to develop and propose nutrient and DO TMDLs for the tidal Murderkill River as presented in this report.

The proposed site-specific DO criteria are as follows:

- Summer daily average DO greater than or equal to 3.0 mg/L;
- Summer daily minimum (1-hour average) DO greater than or equal to 1.0 mg/L; and
- Existing DO standards apply during winter months (daily average of 5.0 mg/L and daily minimum of 4.0 mg/L).

The summer "warm" period is defined as May through September and the winter "cool" period as October through April.

The proposed site-specific nutrient criteria are as follows:

- Annual average TN less than or equal to 2.0 mg/L; and
- Annual average TP less than or equal to 0.20 mg/L.

These proposed site-specific criteria are based on two very important findings that emerged from the Murderkill River studies. First, the high natural turbidity in the tidal Murderkill River that occurs as a result of the high tidal energy in the river significantly suppresses algal production as compared to systems with better water clarity regardless of the concentration of nutrients. The result is that phytoplankton populations (as measured by chlorophyll-a) are light limited as opposed to nutrient limited. That is, nutrient reductions will have limited effect on reducing phytoplankton populations. Therefore, since algal production is light limited, the effect on river DO levels is also minimized due to the associated limited phytoplankton oxygen production and respiration. For these reasons, DO was considered the most important nutrient endpoint (i.e., nutrient related effect) for the tidal Murderkill River as opposed to chlorophyll-a or algal levels. In addition, DO levels have a direct link to aquatic life protection.

Secondly, the extensive acreage of freshwater and tidal marshes in this watershed contributes large loadings of organic carbon and anoxic wetland ebb waters (i.e., leaving the tidal marshes on the outgoing tide) that affect DO levels in the river. In addition, the marshes can be a nutrient sink or source depending on the season or tidal inundation level. The tidal Murderkill River models were used to estimate the summer average impact of the tidal marshes and found that DO decreases from 1.3-2.2 mg/L occurred as a result of the natural organic carbon and low DO loading associated with the tidal marshes. In the middle of the river where minimum DO levels occur, the summer average DO decrease is approximately 2 mg/L. Therefore, DO levels in the tidal Murderkill River are significantly impacted by interactions with the tidal marshes and are the dominant factor controlling DO levels.

In response to these findings, the Murderkill Study Group recommended that:

1. The TMDL allocations for nonpoint sources and for the non-tidal part of the Murderkill River Watershed remain unchanged in order to address impairments in the freshwater portion of the system, especially the upstream ponds and lakes;

2. DNREC amend the Surface Water Quality Standards Regulation to include site-specific DO criteria; and
3. DNREC amend the Surface Water Quality Standards Regulation to include site-specific TN and TP criteria.

Although changes in nutrient concentrations have little impact on DO levels, the Murderkill Study Group decided that there is a continued need to limit the input of nutrients to the tidal Murderkill River and to minimize the downstream impact of nutrients. The proposed nutrient criteria correspond to the maximum nutrient reduction levels from point and nonpoint sources that are practical and achievable. In this respect, the proposed nutrient criteria minimize downstream nutrient impacts and prevent any significant increases in river nutrient levels due to anthropogenic sources.

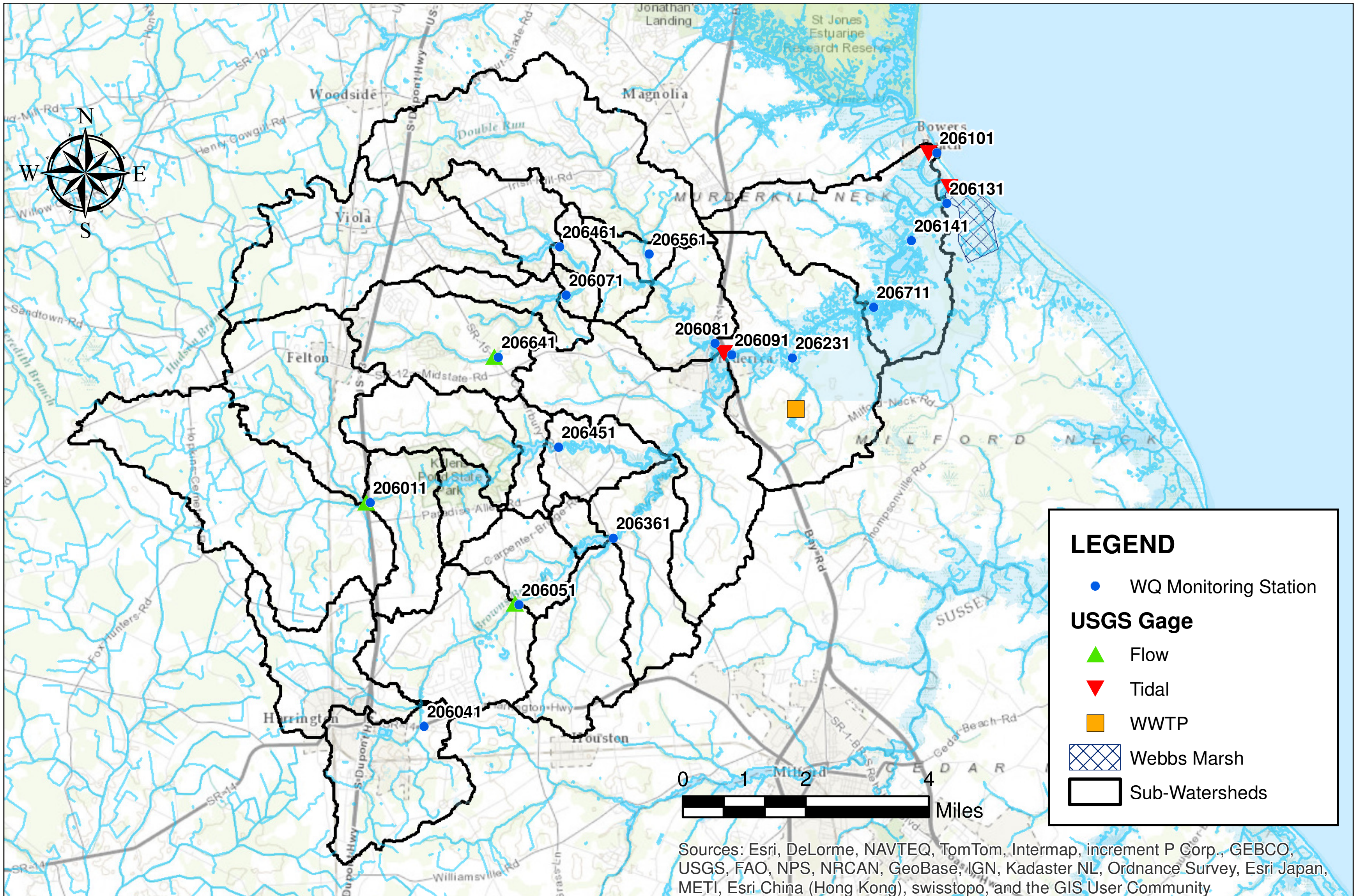

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Figure 1. Murderkill River Watershed Study Area

SECTION 2

MODELING FRAMEWORKS

The Murderkill River modeling framework is comprised of three components: a watershed model; a hydrodynamic model; and a water quality model (HDR|HydroQual, 2013a). The watershed model characterizes watershed processes in the watershed such as rainfall driven runoff and nonpoint source loadings including freshwater stream and lake/pond water quality interactions. The hydrodynamic model simulates the tidal movement of water due to tides and freshwater flow, density driven currents, and meteorology confined by a realistic representation of the systems bathymetry and also calculates salinity and temperature. The water quality model calculates nutrient mediated algal growth and death, DO, the various organic and inorganic forms of nitrogen, phosphorus, silica, and carbon (or BOD). In addition, the water quality model includes a sediment flux sub-model to calculate sediment oxygen demand (SOD) and sediment nutrient fluxes as a function of settling particulate organic matter (POM) and sediment diagenesis. Tidal salt marsh interactions were also included as loading functions based on the nutrient balance studies in Webb's Marsh.

The watershed model used in the study is the Hydrologic Simulation Program FORTRAN (HSPF) that is available with USEPA's multi-purpose BASINS package. It uses rainfall, air temperature, solar radiation, land use patterns, and land management practices to simulate the quantity and quality of runoff from urban, mixed and/or agricultural watersheds. The model results provide runoff flow and nonpoint source loadings to the hydrodynamic and water quality models.

The hydrodynamic model used in the study is the three-dimensional, time-dependent, estuarine and coastal circulation model, Estuary and Coastal Ocean Model (ECOMSED), which has been successfully applied in numerous studies. The water quality model used in the study is a state-of-the-art eutrophication model Row Column AESOP (RCA), which is very similar to the WASP model, and is directly coupled with the hydrodynamic model, allowing computation of water quality within the tidal cycle. In addition, a sediment flux sub-model is also included in the water quality model to allow calculation of SOD and sediment nutrient fluxes in response to settled organic matter and its subsequent decay in the sediment. This coupled hydrodynamic/water quality model has been successfully applied in numerous studies including: St. Jones River, Blackbird Creek, Leipsic River, Smyrna River, Little River and Broadkill River (DE); Delaware River (NJ/PA/MD/DE); South Atlantic Bight (NY/NJ); Jamaica Bay (NY); Hudson-Raritan Estuary (NY/NJ); Long Island Sound (NY/CT); Chesapeake Bay (MD/DE); Massachusetts Bay and Boston Harbor (MA); Upper Mississippi River (MN); San Joaquin River (CA); Tar-Pamlico Estuary (NC); Escambia/Pensacola Bay, Fenholloway River and St. Andrews Bay (FL).

The watershed, hydrodynamic and water quality models were calibrated and validated with data collected by DNREC and USGS over the 2007-2008 monitoring period. The year 2007 was considered as the calibration and year 2008 as the validation with a consistent set of model parameters developed that best represented the observed data. These data include Acoustic Doppler Current Profiler (ADCP) data (velocity, water elevation), temperature, salinity and water quality (nitrogen, phosphorus, carbon, DO, chlorophyll-a) data throughout the Murderkill River watershed. The calibrated and validated watershed, hydrodynamic and water quality models resulted in a reasonable representation of both the complex mixing and circulation patterns observed in the study area and the observed nutrient, phytoplankton, organic carbon, and DO dynamics of the system. The linked watershed, hydrodynamic and water quality models were developed to support continued TMDL and site-specific criteria development in the Murderkill River watershed.

2.1 MODEL SEGMENTATION/DELINEATION

The HSPF model was delineated into 28 sub-watersheds in the Murderkill River watershed based on monitoring station locations, location of lakes and tributary watersheds (Figure 2). In each model sub-watershed, multiple land use types and different model parameters were applied along with stream geometry assigned as a set of functional relationships to flow between variables, such as stream surface area, volume and velocity. Land use information for the year 2007 was used for the watershed modeling and consisted primarily of 85% non-urban land uses (agriculture, wetlands, forest, pasture) with approximately 55% represented as agricultural land use.

An orthogonal, curvilinear modeling grid system was used for the hydrodynamic and water quality models in order to discretize the tidal reaches of the lower portion of the Murderkill River and nearshore Delaware Bay (Figure 3). The model downstream tidal boundary condition extends approximately 4-7 miles into Delaware Bay from the shoreline and 11 miles in the upstream/downstream direction in the bay. These tidal boundary condition segments are presented in Figure 3 as the shaded model cells. The grid system consists of an 89 x 63 segment model grid in the horizontal plane with 6 equally spaced σ-levels in the vertical plane (i.e., 5 vertical segments). In addition to water segments in the model, model segments were also included for the tidal marsh areas (shaded in Figure 3). The extension of the model grid into the bay is aimed at minimizing the bay boundary condition effects on the internal model calculations.

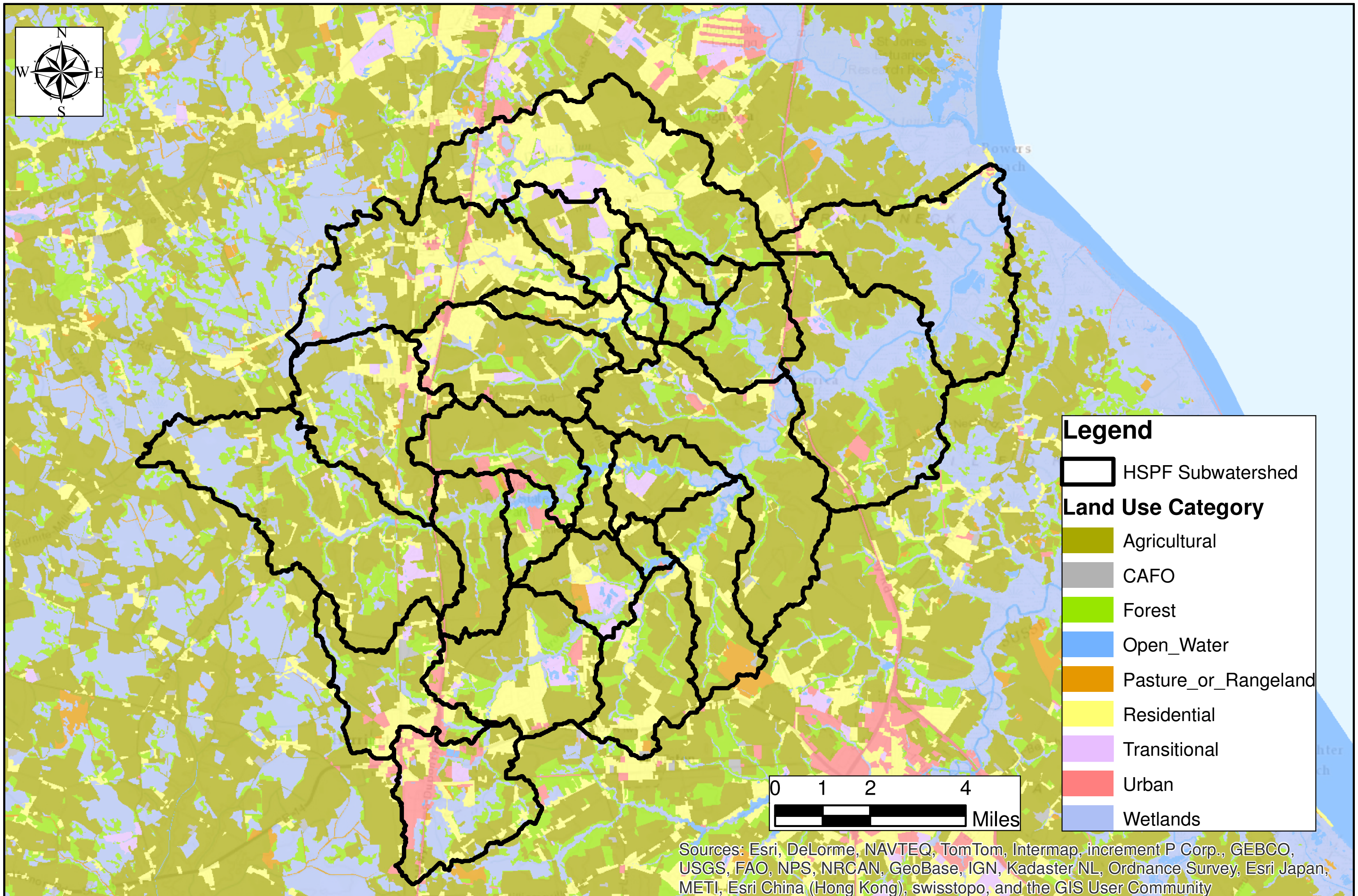

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Figure 2. Murderkill River Watershed HSPF Segmentation

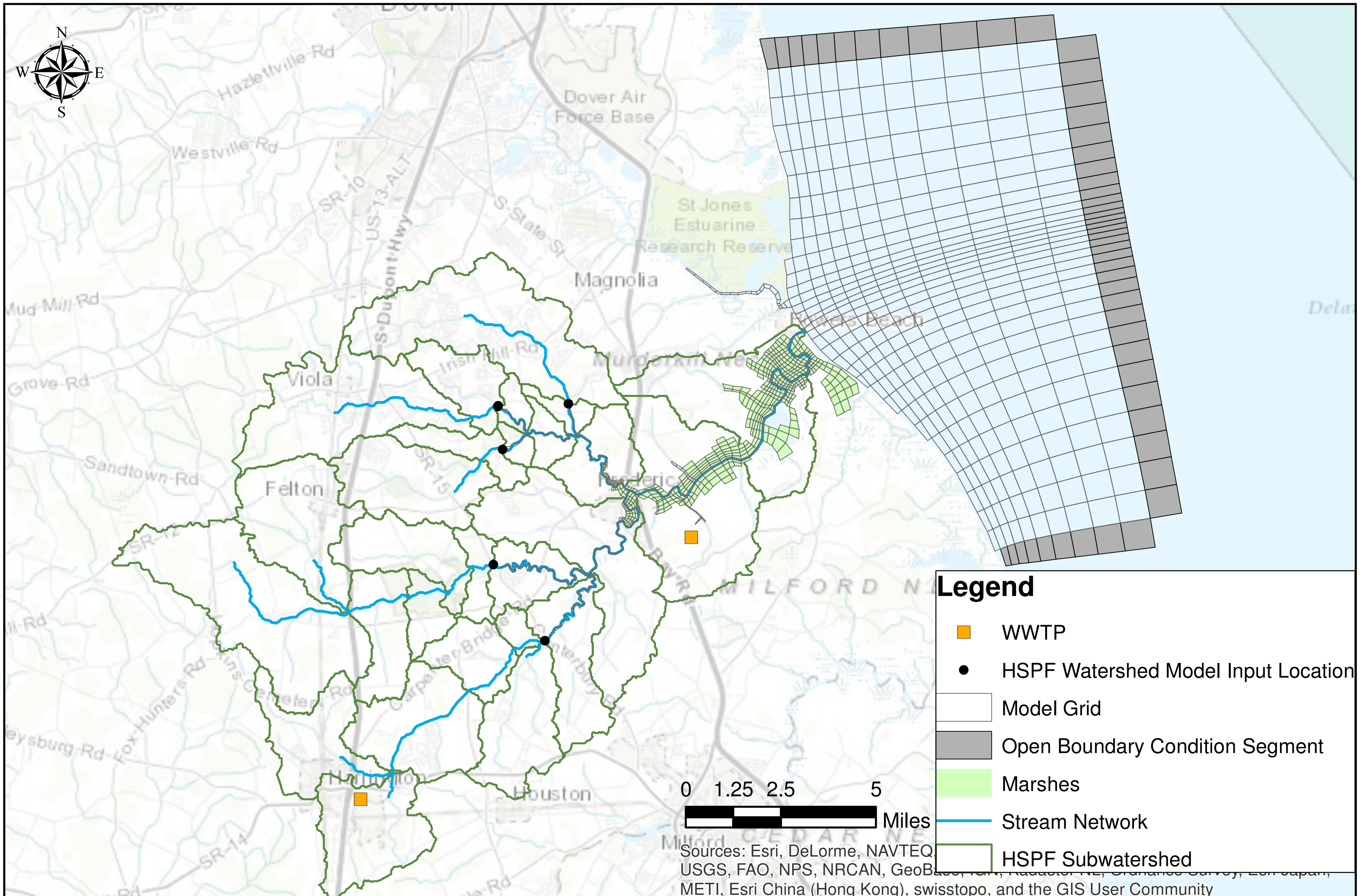

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Figure 3. Murderkill River ECOMSED/RCA Model Grid

SECTION 3

WATERSHED CHARACTERISTICS

3.1 LAND USE

The land use information used in the HSPF watershed model for the year 2007 was obtained from DNREC and is presented in Figure 2. The Murderkill River watershed is primarily non-urban (85%) with approximately 55% agricultural land use for a total area of approximately 62,000 acres (97 mi^2). The 2007 land use information included 47 categories which were regrouped into 10 categories for use in the HSPF model setup (Table 2). Land use areas for the 6 major sub-watersheds are presented in Figure 4.

Table 2. Murderkill River Watershed Land Use Summary

Land Use Type	Area (acres)	Area (mi^2)	% of Total
Agriculture	34,237	53.5	55.4%
Wetlands	8,949	14.0	14.5%
Residential	7,779	12.2	12.6%
Forest	7,077	11.1	11.4%
Urban	1,117	1.7	1.8%
Water	1,088	1.7	1.8%
Transitional	601	0.9	1.0%
Pasture	519	0.8	0.8%
Roadways	273	0.4	0.4%
CAFO	183	0.3	0.3%
Total	61,824	96.6	

3.2 POINT SOURCES

In the Murderkill River watershed there were two active point sources during the 2007-2008 modeling period: Kent County Regional Wastewater Treatment Facility (KCRWTF) and Harrington Sewage Treatment Plant (STP). There were two other point sources in the watershed (Canterbury Crossing and Southwood Acres Mobile Hone Park) that were eliminated before the 2007-2008 modeling period. The KCRWRF discharges into the tidal portion of the river and the Harrington STP discharges near the upstream end of Brown's Branch just east of the Town of Harrington. Given the locations of these two point sources, the KCRWRF flow and loads are assigned in the tidal hydrodynamic/water quality model (ECOMSED/RCA) model and the Harrington STP flow and loads are assigned in the HSPF watershed model. Table 3 presents the average flow and concentration data for each of the parameters from these point sources during the 2007-2008 modeling period. The total nitrogen (TN) and total phosphorus (TP) loads during the modeling period for the Harrington STP are 66.4 lb/d TN and 0.9 lb/d TP; and for the KCRWRF are 553.3 lb/d TN and 173.1 lb/d TP. Although the Harrington STP loads are less, this discharge is located in the headwaters of Browns Branch and given the high effluent NH_3 concentrations has a large impact on toxicity and DO levels in Browns Branch. Since the KCRWRF discharge is located in the tidal portion of the river with much greater rates of tidal mixing, the water quality impacts are less with current TP loads still being significant in the tidal river.

Table 3. Point Source Load Summary (2007-2008)

Parameter	Harrington STP	KCRWTF
Flow (MGD)	0.45	10.7
$CBOD_5$ (mg/L)	4.3	3.2
DO (mg/L)	n/a	8.4
TSS (mg/L)	6.9	6.2*
TN (mg/L)	17.7	6.2
NH_3 (mg/L)	17.6	1.0
NO_2+NO_3 (mg/L)	n/a	3.7
TP (mg/L)	0.24	1.94
PO_4 (mg/L)	n/a	1.66

* - VSS data

Septic systems are also nutrient sources in the watershed both through groundwater contributions but also directly to the streams from failing or improperly operated systems. Therefore, septic nutrient loads were assigned in the model based on the location of septic systems throughout the watershed (2005 data) as provided by DNREC. Figure 5 presents the septic system locations along with the HSPF model sub-watershed segmentation. For each sub-watershed segment, NO_2+NO_3 and PO_4 loads from septic tanks were estimated and assigned as point sources in the HSPF model as a constant source. Septic loads were computed for each sub-watershed by multiplying the number of septic systems by the average number of people served by each system, typical septic overcharge flow rate, failure rate and concentration. A final scale factor of 25% of the original calculated septic system load was determined during the calibration process, which may represent the percentage of failing septic systems. The total septic system loads were 14.0 lb/d NO_2+NO_3 and 2.8 lb/d PO_4.

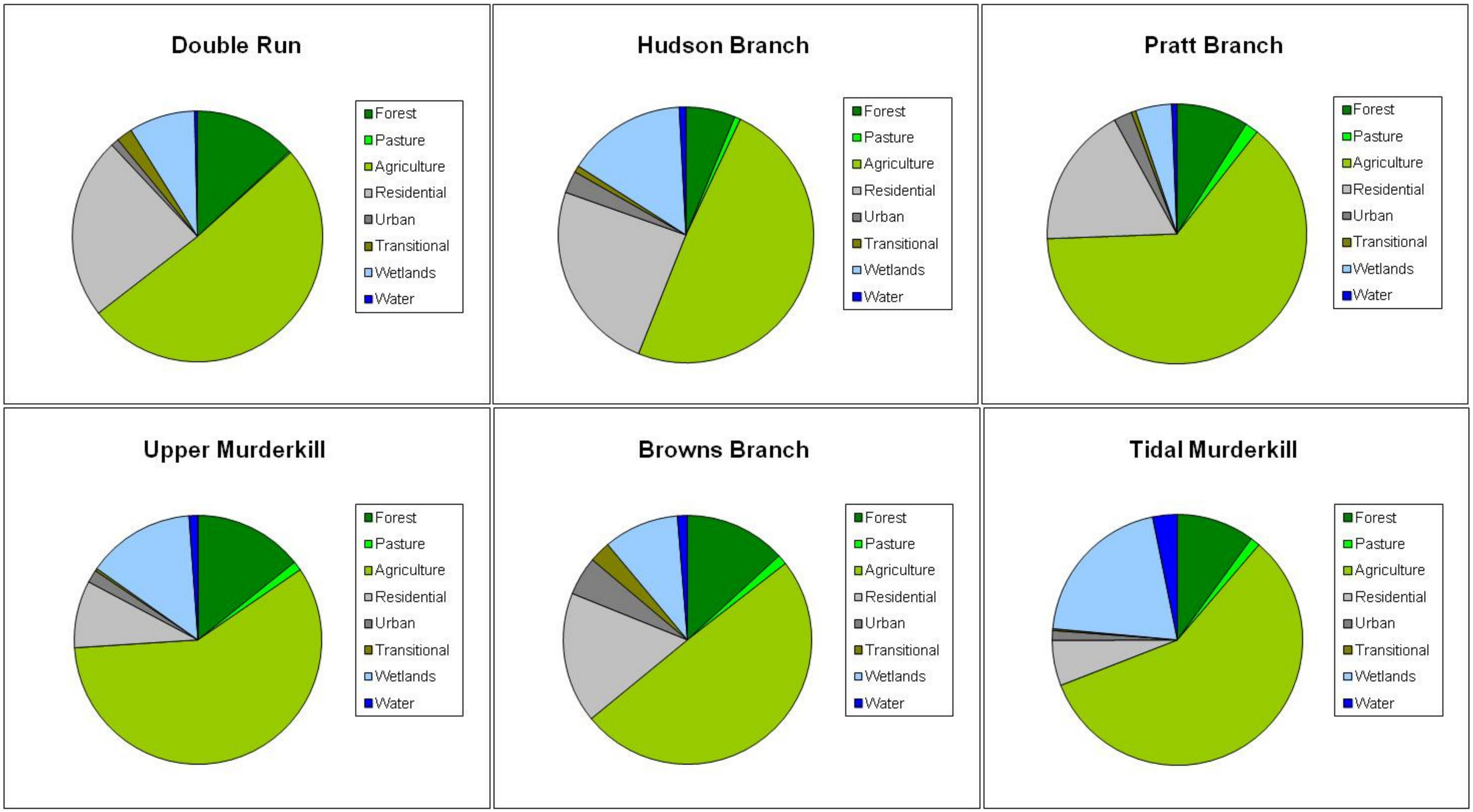

Figure 4. Murderkill River Watershed 2007 Land Use for Major Sub-watersheds

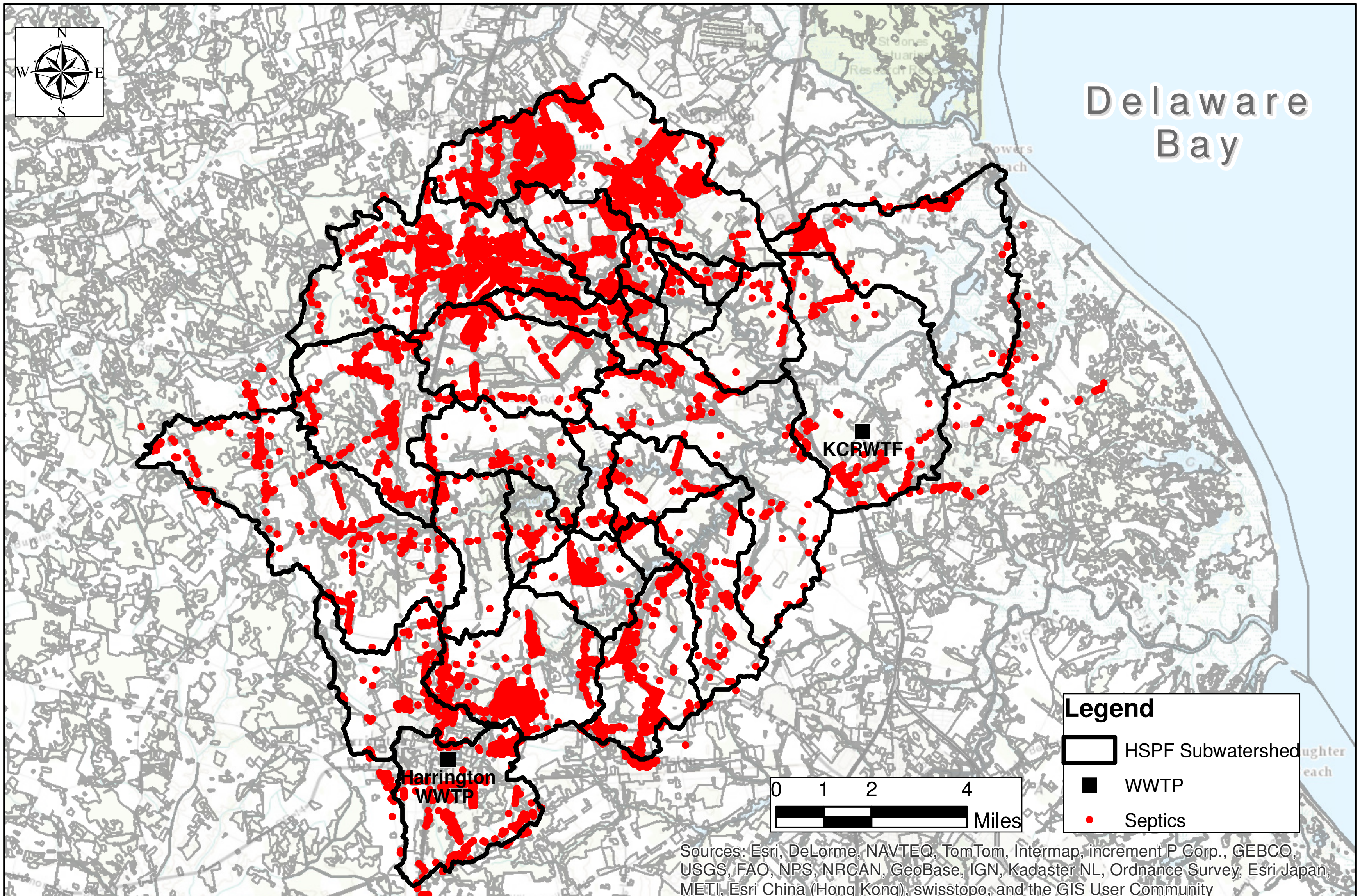

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Figure 5. Murderkill River Watershed Septic System Distribution

SECTION 4

WATERSHED MONITORING

Five project specific studies were completed to support the Murderkill River Study that provided data to support the water quality model setup and calibration/validation efforts. These data included: the USGS continuous monitoring at Bowers Beach (#01484085) and Frederica (#01484080); long term BOD (LTBOD) studies completed on river samples (DNREC) and KCRWTF effluent (KCDPW); algal production studies completed at seven tidal river stations (Sharp, 2011); tidal marsh nutrient, carbon and DO deficit load studies completed in Webb's Marsh (Ullman, W., et. al, 2013); and sediment flux studies completed on cores in the tidal river (Chesapeake Biogeochemical Associates, 2010).

The LTBOD studies were used to develop a relationship between the more frequently measured BOD_5 parameter and ultimate BOD (BODu), which is used for model calibration and conversion of model inputs to carbon units that are needed for model setup. This is required for both river and KCRWTF effluent samples. In addition, the LTBOD studies provide an estimate of the BOD oxidation rate, which is used to assign this constant in the model. LTBOD tests were completed at 16 river stations (5 freshwater sites, 4 lake/pond sites, 7 tidal sites) during 6 sampling events in 2007-2008. For the KCRWTF effluent, LTBOD tests were completed 15 times on a roughly monthly basis in 2007-2008.

The algal production data collected by the University of Delaware (Sharp, 2011) was used for adjusting the model phytoplankton growth rate during calibration/validation so that model calculated ambient growth rates compared favorably to the algal production data. Algal production tests were completed at seven tidal river stations from Bowers Beach to Frederica on 22 dates in the 2007-2008 modeling period. Primary production was estimated through incubation of samples over a 24-hour period at varying light levels to simulate different depths in the water column from the surface down to the 1.5% light depth.

The tidal marsh studies completed in Webb's Marsh (Ullman, W., et. al, 2013) provided estimates of nutrient, carbon and DO deficit loads that were then extrapolated to the rest of the Murderkill River tidal marsh area for use in assigning these loads in the model. The DO deficit load represents the difference between the ebb DO levels and the flood DO levels. Typically, the flood DO levels (incoming) are greater than the ebb DO levels (outgoing) due to oxygen consumption in the marsh and this process was reflected in the model input setup. The tidal marsh studies completed involved measurement of the various forms of organic and inorganic nitrogen and phosphorus, organic carbon, chlorophyll-a (chl-a), silica and suspended solids. For the organic forms both particulate and dissolved fractions were measured. The data were collected near the mouth of Webb's Marsh with the Murderkill River approximately every hour over roughly two to three complete tidal cycles in July 2007, October 2007, April 2008, May 2008 and August 2008. In addition, the USGS had a continuous gage located at the same location that recorded salinity, temperature, DO, water elevation and tidal volume flux over the 2007-2008 modeling period. Through analysis of both the water quality data and USGS tidal data at the mouth of the marsh, nutrient, carbon and DO deficit loads were calculated for each monitoring period. These loads were used to define the tidal marsh loads in the model by normalizing them with the active Webb's Marsh area (157 acres) and extrapolating to the rest of the Murderkill River tidal marsh area based on the LiDAR study (McKenna, 2013) that developed tidal marsh areas by zones in the river.

The sediment flux studies completed in the tidal Murderkill River (Chesapeake Biogeochemical Associates, 2010) provided estimates of sediment oxygen demand (SOD) and nutrient fluxes at four locations in the main stem of the river (July 2007) and six tidal marsh sites (July 2007 and April 2008). SOD and nutrient fluxes were determined from the collection of sediment cores that were incubated for approximately 5 hours with the measurement of DO and nutrients over time completed. From these data, regressions are completed to determine the sediment areal uptake or production rate of oxygen, NH_3, NO_2+NO_3, PO_4, N_2 gas and silica. The river data are used for calibration/validation of the sediment flux model and the marsh data used for an initial starting estimate of the tidal marsh denitrification rate. The final tidal marsh denitrification rate was determined from model calibration/validation and was assigned at 15 $gN/m^2/yr$.

In addition, continuous tidal monitoring for salinity, temperature, DO, pH, water elevation and volume flux was completed by the USGS in the tidal Murderkill River near Frederica and at Bowers Beach along with the installation of three stream gaging stations to monitor flow in the watershed on the Murderkill River, Pratt Branch and Browns Branch. Increased sampling in the Murderkill River watershed by DNREC was also completed for this study. The DNREC sampling frequency was increased to bi-weekly or monthly with the addition of a few additional monitoring locations.

4.1 OVERALL WATER QUALITY ASSESSMENT

In general, the water quality data analysis in the tidal Murderkill River watershed indicates that the watershed experiences low DO levels, less than the State WQS daily average of 5 mg/l and minimum of 4 mg/L at many stations. Potential oxygen demands include tidal marsh interactions, sediment oxygen demand (SOD), BOD oxidation, ammonia nitrification and/or algal respiration. These oxygen demands can originate from point and nonpoint sources but also potentially from tidal marsh loading of organic material. The data indicate sufficient nutrient concentrations at most of the stations to support algal growth. Table 4 presents a summary of the available tidal river water quality data as presented in the DNREC 2012 Integrated 305(b) and 303(d) List Report. These data show that DO levels are lowest in the middle of the river with TN levels generally decreasing in the downstream direction and TP levels decreasing in the upstream and downstream directions from roughly station 206213.

Table 4. Summary of Data for 305(b) and 303(d) Report[1]				
Tidal Station	TN (mg/L)[2]	TP (mg/L)[2]	DO (mg/L)[3]	# of DO samples <4 mg/L
206101 (Bowers Beach)	1.7	0.23	5.6	0
206131 (Webbs Landing)	1.6	0.20	5.3	2
206141 (Milford Neck)	2.1	0.24	3.9	10
206711 (Power Lines)	2.2	0.28	3.3	7
206231 (KC Canal)	3.3	0.80	3.4	15
206091 (Rte. 113)	3.0	0.27	4.1	8
206081 (Rte. 12)	2.8	0.28	4.6	5

1 – Data period is 9/1/2006 through 8/31/2011
2 – 5-year average
3 – 10^{th} percentile

4.2 SOURCES OF POLLUTION

Nonpoint source pollution can be defined as pollution that occurs over large areas as a result of common practices and land uses. Unlike a point source that discharge loads into a water body at a specific location, nonpoint sources will affect a water body at spatially variable locations, such as ground water seepage or agricultural runoff along a given stream length. In order to quantify nonpoint sources in the Murderkill River watershed, land areas were classified according to land use, pollutant build-up and wash-off coefficients, and groundwater concentrations. The land use distribution in the Murderkill River watershed was generalized into the groups shown in Table 2: agriculture, wetland, residential, forest, urban, water, transitional, pasture, roadways, and combined animal feeding operations (CAFO). Each of these land uses has different possible sources of pollution that are deposited directly or indirectly to the water system.

Approximately 55% of the Murderkill River watershed was classified as agriculture, including cropland, farm related buildings, idle fields, and orchard and nursery land uses. Possible nonpoint sources of pollution from these areas include nutrients from farm fields, organic material from plants, nutrients from applied fertilizers, and particulate and dissolved nutrients in runoff.

Wetland areas account for 15% of the watershed area and are home to many species of plants and wildlife that produce organic and nutrient material. The majority of the wetland area is associated with the tidal marshes that fringe the tidal river. Loadings from these wetland areas are assigned separately in the tidal river model based on data from the tidal marsh studies completed.

Residential and urban land uses often increase nonpoint pollution due to decreased perviousness and increased human development. The residential land use contains single and multiple family dwellings along with mobile home parks. The urban land use contains junk/salvage yards, mixed urban, retail/wholesale, commercial, communication, industrial, institutional/government, utilities, and recreational. Among the causes of pollution from residential/urban land uses are nutrients in runoff from impervious surfaces, nutrients and bacteria from septic systems, nutrients from residential fertilizers, industrial wastes and domestic pet wastes. Approximately 14% of the Murderkill River watershed is residential/urban land use.

Forested areas account for a little more than 11% of the watershed. The types of forest are deciduous, mixed and evergreen. Nutrients from wild animals and organic material from plants are common sources of nonpoint pollution.

Transitional, pasture, roadway and CAFO land uses each comprise less than 1% of the watershed and can provide nutrient and organic material runoff from these land surfaces.

Based on the land use data, the Murderkill River watershed is primarily non-urban (85%) and, therefore, NPSs are an important source of pollution in the watershed. There were two (2) active NPDES permitted PSs in the watershed (Harrington STP and KCRWTF) during the monitoring and model calibration/validation period of 2007-2008. Information on these two PSs is presented in Section 3.2.

SECTION 5

SCOPE AND OBJECTIVES OF THE AMENDED TMDL ANALYSIS

To comply with the newly proposed site-specific DO and nutrient criteria for the tidal Murderkill River, DNREC is proposing to amend the Waste Load Allocation (WLA) component of the 2005 TMDL for TN, TP and DO for the Murderkill River watershed. The proposed WLA amendment is the result of various load reduction analyses, which were conducted using the Murderkill River Watershed Model as a predictive tool. The proposed WLA amendment is designed such that, when implemented, all segments of the tidal Murderkill River will achieve the site-specific water quality standards for TN, TP and DO. Monitoring in the watershed should continue to assess the impact of load reductions and to determine the associated water quality improvements. In this manner, an adaptive management approach can be followed in the watershed. In addition, an implicit margin of safety (MOS) was used for the TMDL due to conservative assumptions and model results from the modeling.

In order to complete this WLA amendment, and as mentioned earlier, mathematical models of the Murderkill River watershed were developed. These mathematical models include a landside watershed model to calculate nonpoint source (NPS) runoff and quality, a hydrodynamic model to calculate the movement of water in the tidal reaches of the Murderkill River, and a water quality model that is coupled to the hydrodynamic model to calculate water quality in the tidal reaches of the river. Details about the TMDL model and site-specific criteria development efforts are presented in the following reports:

- Murderkill River Watershed TMDL Model Development and Calibration (HDR|HydroQual, 2013a); and
- Tidal Murderkill River Site-Specific Nutrient and Dissolved Oxygen Criteria (HDR|HydroQual, 2013b).

5.1 TOTAL MAXIMUM DAILY LOADS AND THEIR ALLOCATIONS

The calibrated and validated Murderkill River models were used to determine TMDLs for the watershed. This effort involved completing various model load reduction scenarios to ultimately arrive at a load reduction scenario that meets the newly proposed site-specific criteria. As part of the site-specific criteria development effort, a number of model scenarios were completed to assess water quality changes due to: different loading sources; the effect of different KCRWTF treatment levels; and the estimation of a “natural background” condition. Based on the model scenarios that were completed, the following load reductions or watershed conditions were used to develop the TMDL scenario for the Murderkill River watershed.

- The Harrington WWTP load to Browns Branch was removed as a result of this WWTP coming off-line and the wastewater being diverted to the KCRWTF for treatment.
- The KCRWTF load was modified to reflect the enhanced nutrient removal (ENR) treatment upgrade planned at the facility.
- The watershed loads were reduced based on the 2005 TMDL and included a 30% reduction for nitrogen and 50% reduction for phosphorus. These load reductions also included an associated 40% reduction in watershed nonpoint source carbon loads.
- Tidal marsh loads were not changed from the calibration/validation period to represent the existing conditions and the belief that these loads will not change significantly in the future.
- The downstream Delaware Bay boundary conditions assigned in the model were not changed for the TMDL condition.
- Failing septic system loads were removed to reflect properly operating septic systems (i.e., no system failures).

The results of these PS and NPS load reductions were used to establish the proposed nutrient and DO TMDLs for the Murderkill River. In these analyses, meeting the proposed site-specific water quality standards for DO and nutrients in tidal Murderkill River reflect achieving the designated uses in the river.

5.2 TMDL ENDPOINTS

For nutrients, the proposed site-specific nutrient criteria were considered as annual averages of 2 mg/L TN and 0.2 mg/L TP, respectively. These targets were considered in the tidal reaches of the watershed. The annual average approach was chosen because nutrient effects on algae are not immediate, that is sufficient time is required for the consumption of nutrients by algae in increasing their biomass. Given the nature of the streams, lakes, ponds, and tidal reaches in the Murderkill River watershed, an annual average time period was considered suitable for assessing nutrient loads for TMDL development.

For DO, the proposed site-specific DO criteria considered were a summer daily average DO greater than or equal to 3.0 mg/L and summer daily minimum (1-hour average) DO greater than or equal to 1.0 mg/L. During the winter, the existing marine DO standards were considered (daily average of 5.0 mg/L and daily minimum of 4.0 mg/L).

5.3 TMDL MODEL OUTPUT PRESENTATION

The model output for TN, TP, chlorophyll-a and DO are presented in a series of figures for comparing the TMDL load reduction scenario to the proposed site-specific criteria or standards. These model output figures are developed for the 303(d) listed tidal reach DE 220-001 (lower Murderkill River from the confluence with Spring Creek to the mouth at Delaware Bay) at a number of monitoring locations. In the marine (tidal) reach, the model output are presented at the six tidal monitoring stations (see Table 4) and also in tidal river zones that allowed consideration of model output variability within the zones.

These tidal river zones are centered around tidal DNREC monitoring stations in the river to aid with future water quality compliance assessments. Table 5 and Figure 6 present the tidal river zones and DNREC monitoring stations with these zones used to present the model results. It should be noted that with regard to DO levels, zones 5 and 6 have the lowest DO among all zones and are considered to be the critical segments where the DO sag occurs in the river.

Figures 7 to 13 present the model output for the calibration/validation period and for the TMDL scenario as time-series for TN, dissolved inorganic nitrogen (DIN), TP, dissolved inorganic phosphorus (DIP), chl-a and DO at the seven tidal river stations. The black line in these figures represents the calibration/validation period and the blue line represents the TMDL scenario. These figures show large reductions in TN during the winter/spring period due to watershed nitrogen reductions and large reductions in TP during the summer/fall period due to the KCRWTF phosphorus reductions. Chl-a decreases are minimal because algal growth is limited by light in the river and that nutrient levels are well above algal growth limiting levels. DO increases are also minimal because DO levels in the tidal river are primarily driven by the influence of the extensive tidal marshes.

Table 5. Tidal River Zones

Tidal River Zone	DNREC Station
1	Bowers Beach (#206101)
2	Webbs Landing (#206131)
3	Milford Neck (#206141)
4	Power Lines (#206711)
5	KC Canal (#206231)
6	Bay Road (#206091)
7	No station available

5.4 INTERPRETATION OF RESULTS

The load reduction scenarios were based on the 2005 TMDL update and numerous model scenarios analyzed during the development of the proposed site-specific nutrient and DO criteria for the tidal Murderkill River. The watershed and point source load reductions along with the other conditions used for the TMDL scenario are discussed in Section 5.1.

The TMDL model scenario results were processed to develop annual average TN and TP concentrations for each tidal river zone. These results are presented in Tables 6 and 7 and show that both the site-specific TN (2 mg/L) and TP (0.2 mg/L) criteria are attained in the river. The annual average TN levels ranged from 0.99-1.85 mg/L with the lower levels calculated near the mouth of the river. The TMDL resulted in TN reductions of 7-20% as compared to the 2007-2008 conditions. The annual average TP levels ranged from 0.089-0.158 mg/L with the lower levels calculated near the mouth of the river and in the upstream reach above the KCRWTF discharge canal. The TMDL resulted in TP reductions of 36-57% as compared to the 2007-2008 conditions.

Table 6. Annual TN Model Results (mg/L)

River Zone	Calibration/ Validation	TMDL (F1) Scenario
1	1.06	0.99
2	1.25	1.17
3	1.51	1.39
4	1.84	1.66
5	2.02	1.78
6	2.22	1.84
7	2.32	1.85
Average	1.75	1.53

Table 7. Annual TP Model Results (mg/L)

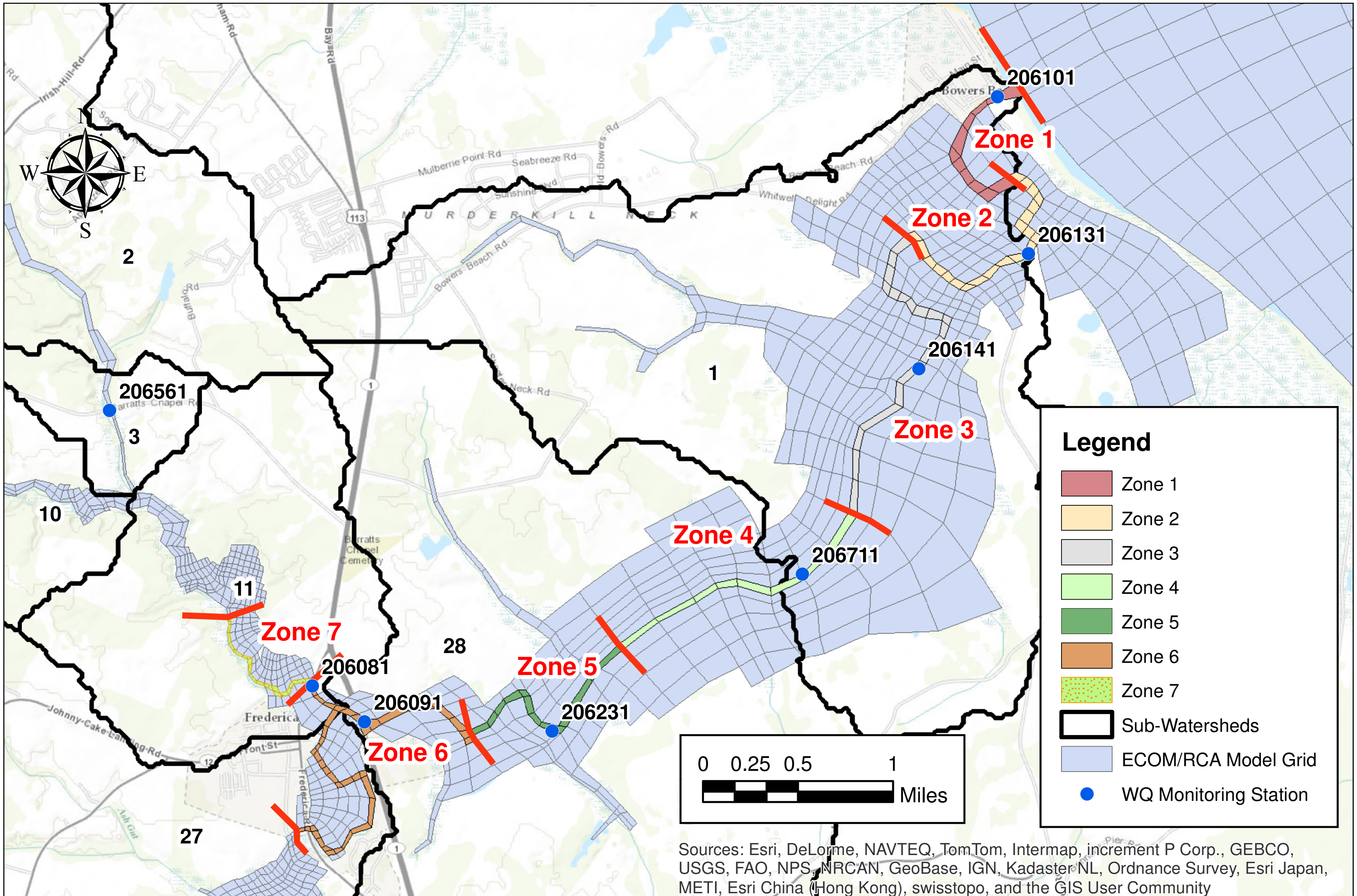
River Zone	Calibration/ Validation	TMDL (F1) Scenario
1	0.139	0.089
2	0.208	0.114
3	0.285	0.139
4	0.355	0.158
5	0.365	0.157
6	0.310	0.134
7	0.265	0.113
Average	0.275	0.129

Figure 14 presents the model DO results for the TMDL scenario as probability distributions by river zone (colored circles) for the site-specific summer daily average and daily minimum DO criteria and the existing winter DO standards. It should be noted that overall the model under-calculates summer DO levels by 0.8 mg/L in the calibration/validation near the middle of the river and, therefore, this model bias is considered when assessing compliance with the proposed site-specific DO criteria. This figure presents the proposed site-specific DO criteria and standards as the horizontal dashed lines, and the 10th percentile as the vertical solid line.

Compliance with the proposed site-specific DO criteria was based on the 10th percentile of the model results. Use of the 10th percentile model results was considered appropriate because of the highly variable nature of the tidal Murderkill River due to tidal interactions between the river and tidal marshes, along with meteorological events that can inundate the marshes for extended periods of time causing increased marsh loadings and subsequent effects on river DO levels. For example, the May 2008 storm that was captured by the marsh monitoring experienced tidal water levels that were about 0.5 meters greater than typical high tides and persisted continuously for about 2-3 days. This prolonged period of tidal marsh inundation resulted in much greater than normal marsh loads of nitrogen, phosphorus, carbon and DO deficit. Based on the marsh monitoring from May 14-15, 2008, the total organic nitrogen loads were about 13 times greater than the other four monitoring events, for total organic phosphorus about 10 times greater, and for total organic carbon about 30 times greater. Given the natural variability in the tidal Murderkill River, compliance with the proposed site-specific DO criteria will be based on the 10th percentile model results.

The model results show that the existing winter DO standards (daily average of 5 mg/L and daily minimum of 4 mg/L) will be achieved in the river at all times in all river zones. During the summer period, 10th percentile model results indicate that the proposed daily minimum DO criteria of 1 mg/L will be met in all zones. Based on the 10th percentile model results, the proposed summer daily average DO criteria of 3.0 mg/L is met in all zones except zones 4 to 7. In these zones, the 10th percentile daily average DO is 2.60, 2.25, 2.41 and 2.83 mg/L, respectively. Considering the model under-calculation bias of 0.8 mg/L (i.e., model DO results are 0.8 mg/L lower than observed data), it can be concluded that the TMDL scenario meets the proposed criteria in all zones when applying the model bias.

Based on these results, the TMDL scenario that includes watershed nutrient TMDL reductions, repair of failing septic systems, removal of the Harrington STP, and implementation of ENR at the KCRWTF indicates compliance with the proposed site-specific summer daily average and daily minimum DO criteria, existing DO standards in the winter, and the proposed site-specific nutrient criteria for the tidal Murderkill River.



HDR | HydroQual

Figure 6. Tidal Murderkill River Zones

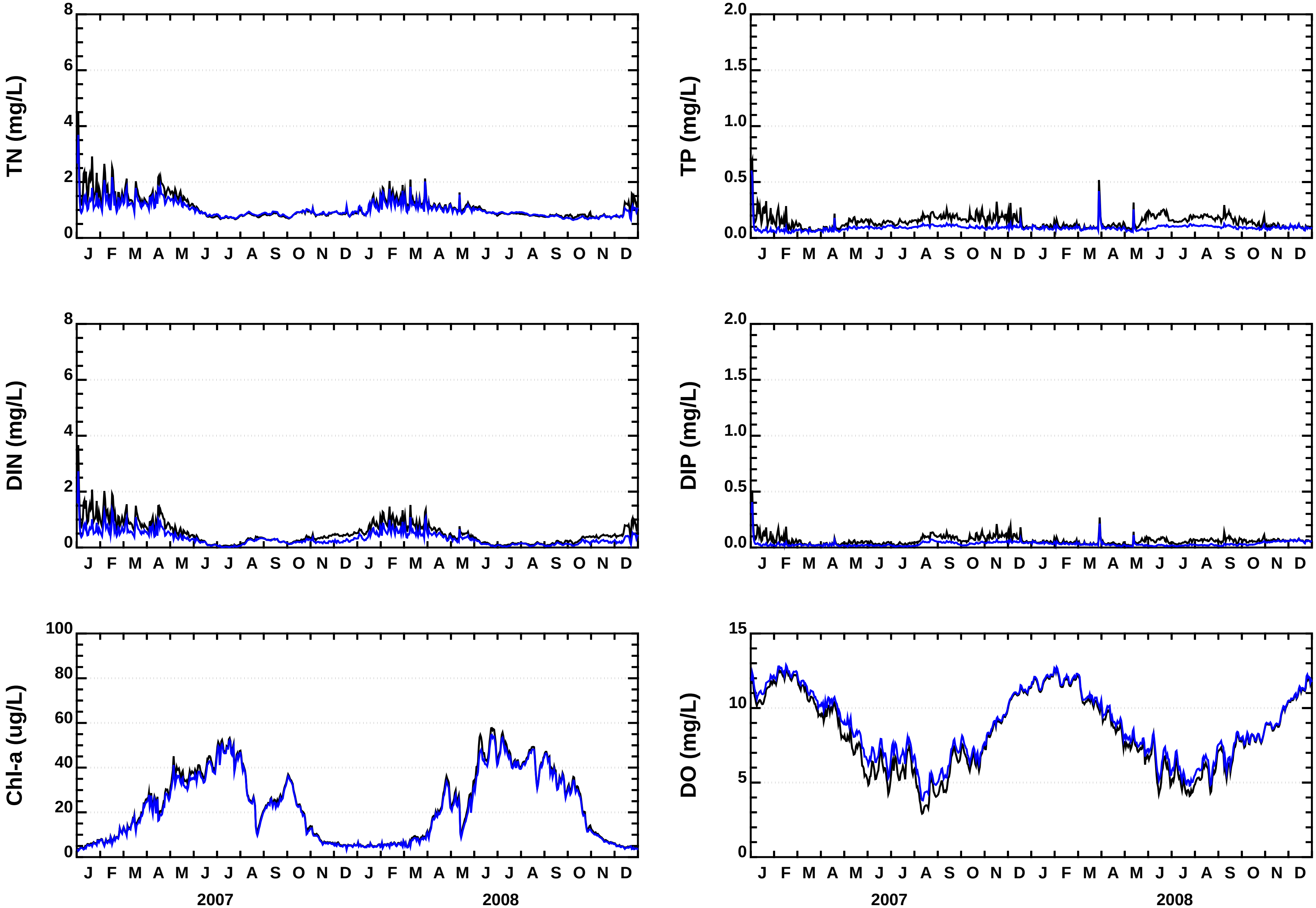


Figure 7. Murderkill River TMDL Loading Scenario Results Bowers Beach (206101)

(Black - Calibration, Blue - TMDL (F1) Scenario)

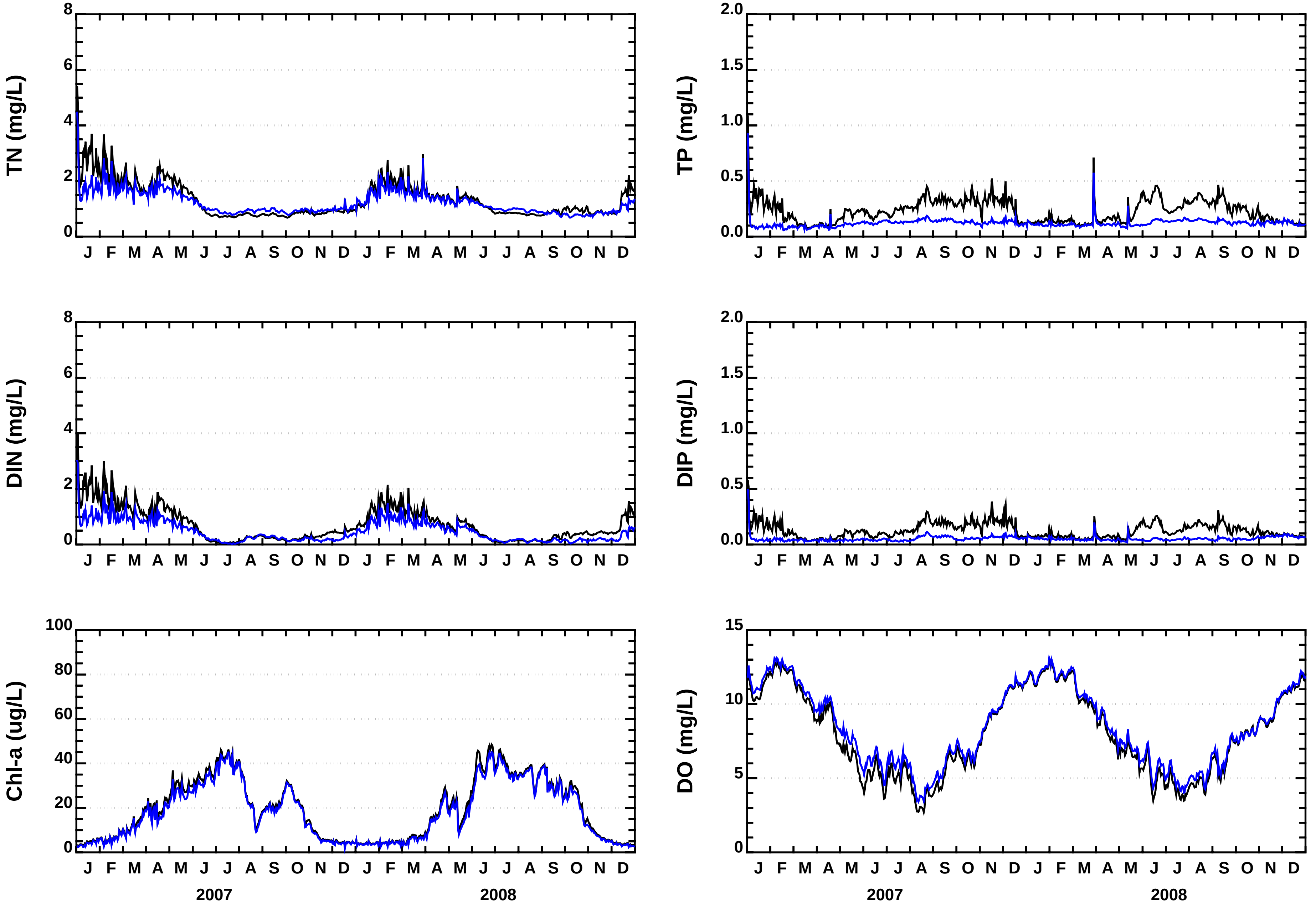


Figure 8. Murderkill River TMDL Loading Scenario Results Murderkill River at Webb Landing (1.25 Miles from Mout

(Black - Calibration, Blue - TMDL (F1) Scenario)

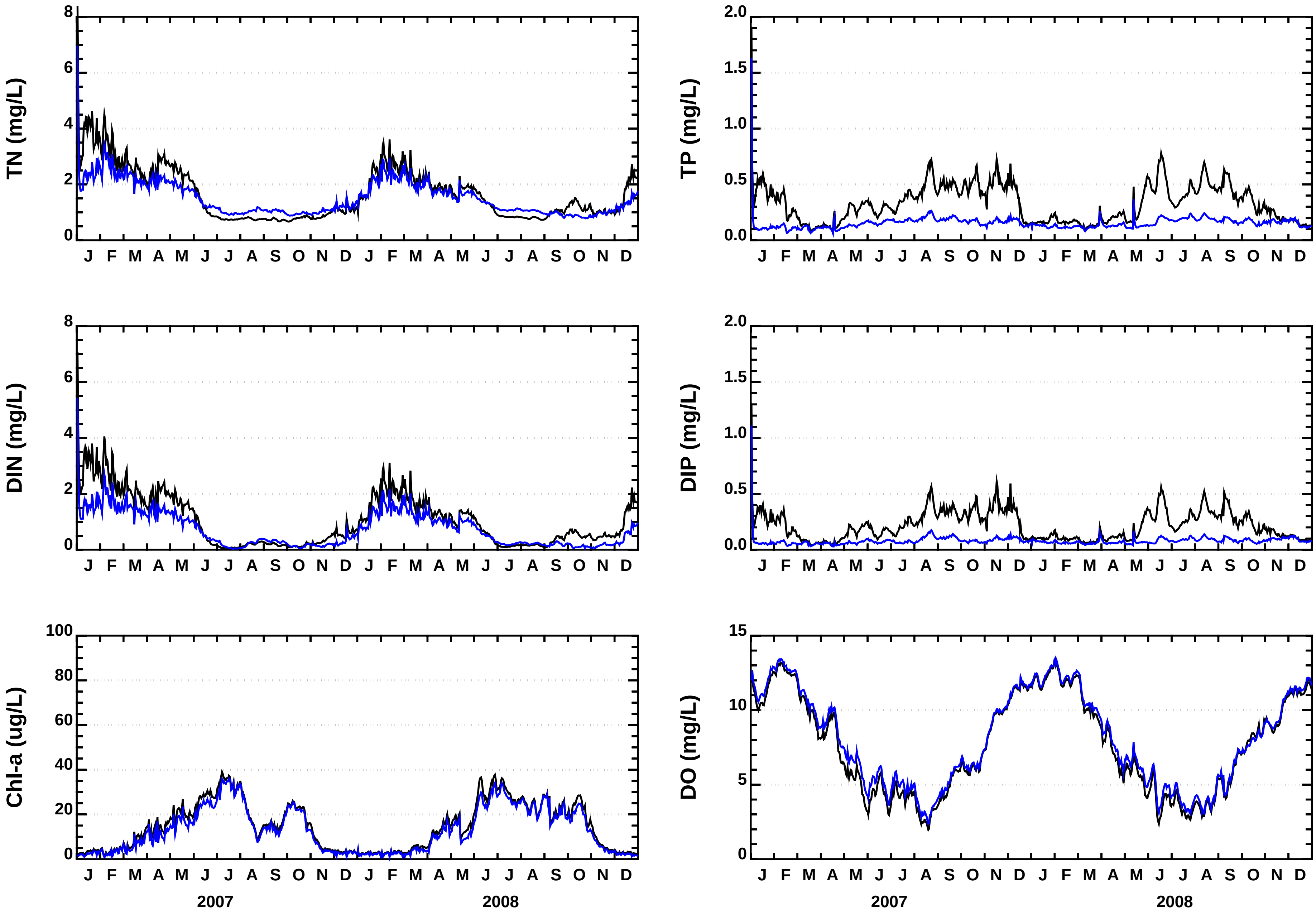


Figure 9. Murderkill River TMDL Loading Scenario Results Milford Neck Wildlife Levee (206141)

(Black - Calibration, Blue - TMDL (F1) Scenario)

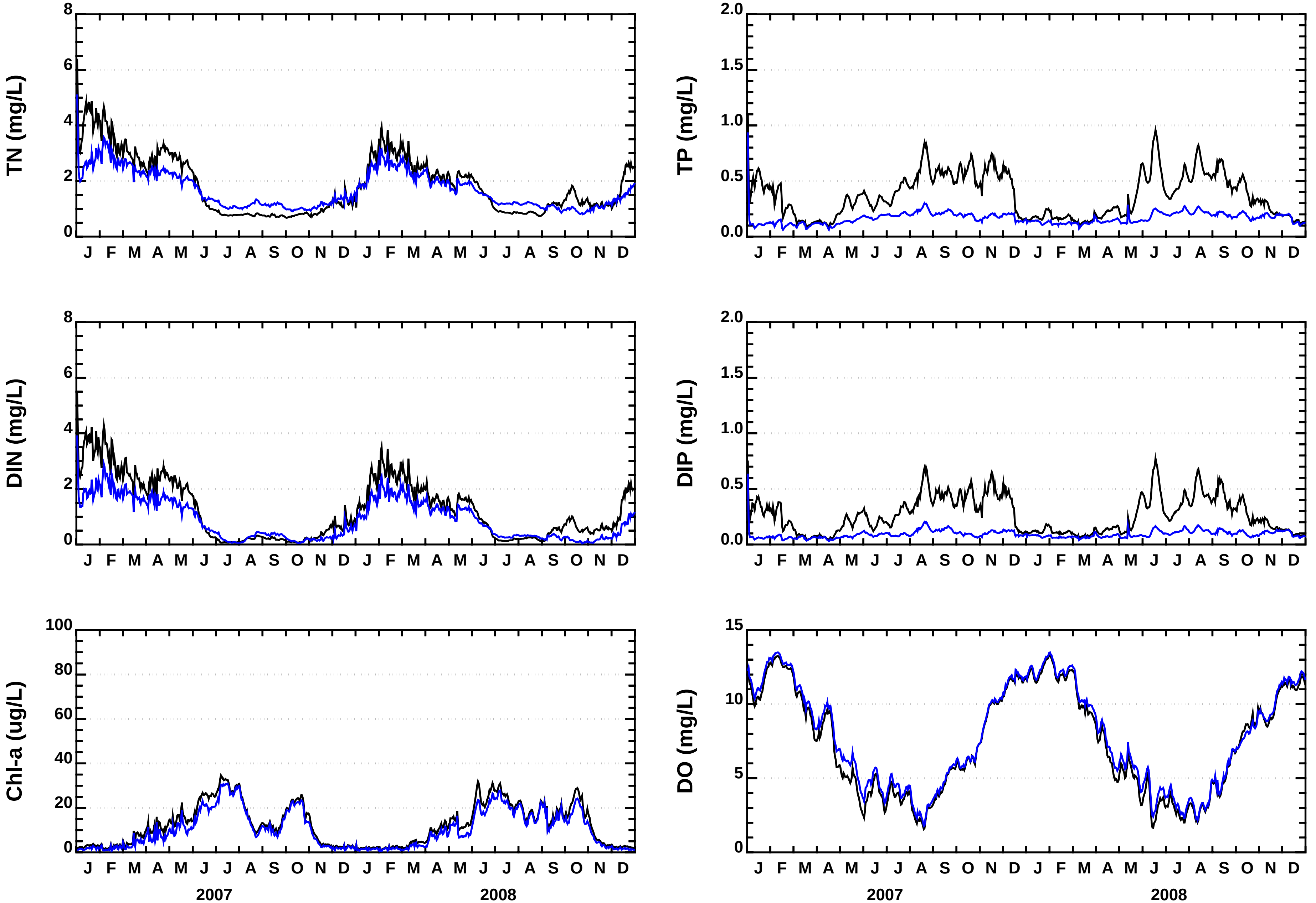


Figure 10. Murderkill River TMDL Loading Scenario Results Murderkill River near Power Lines (4.45 River Miles) (2

(Black - Calibration, Blue - TMDL (F1) Scenario)

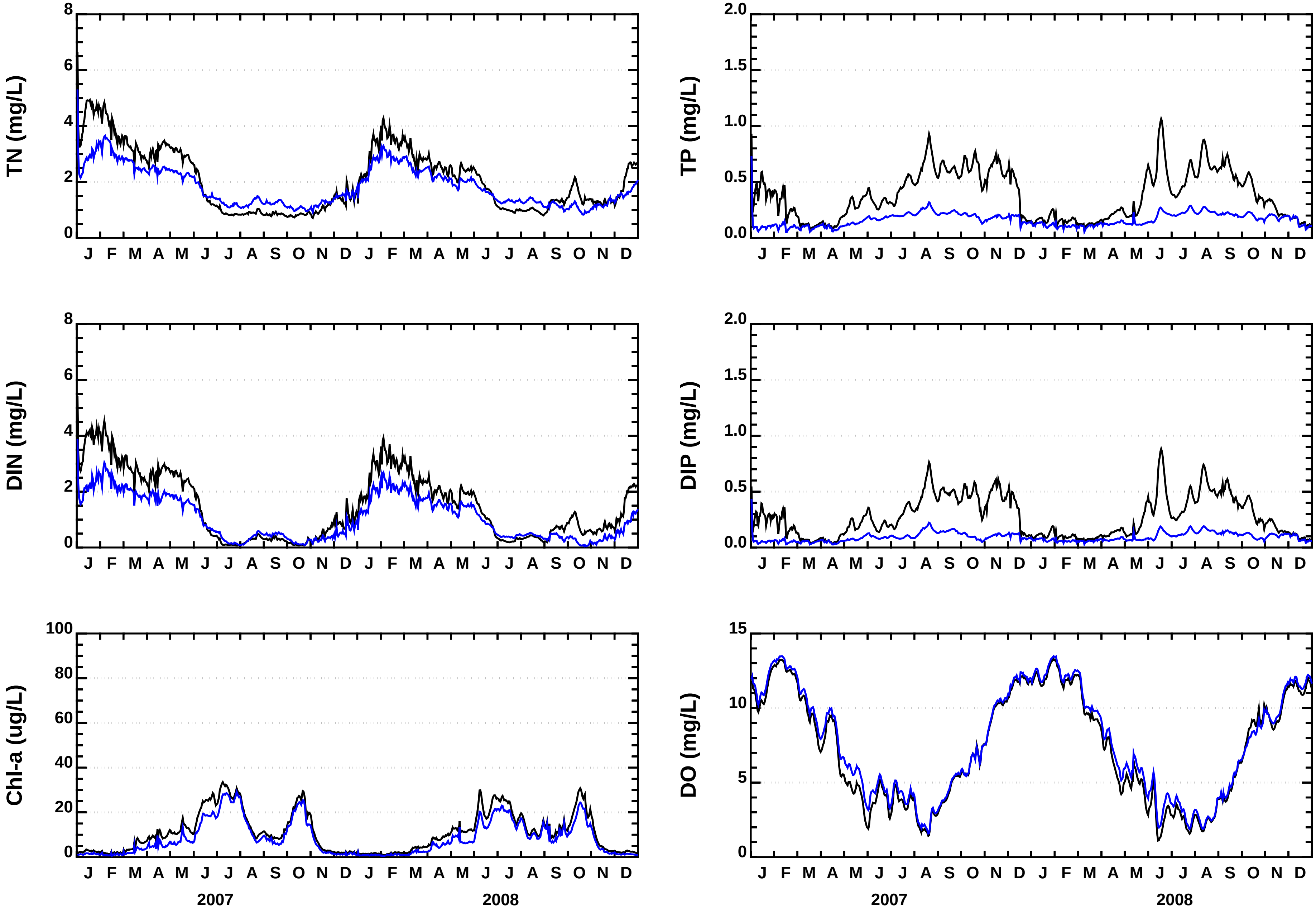


Figure 11. Murderkill River TMDL Loading Scenario Results Kent County Canal (206231)

(Black - Calibration, Blue - TMDL (F1) Scenario)

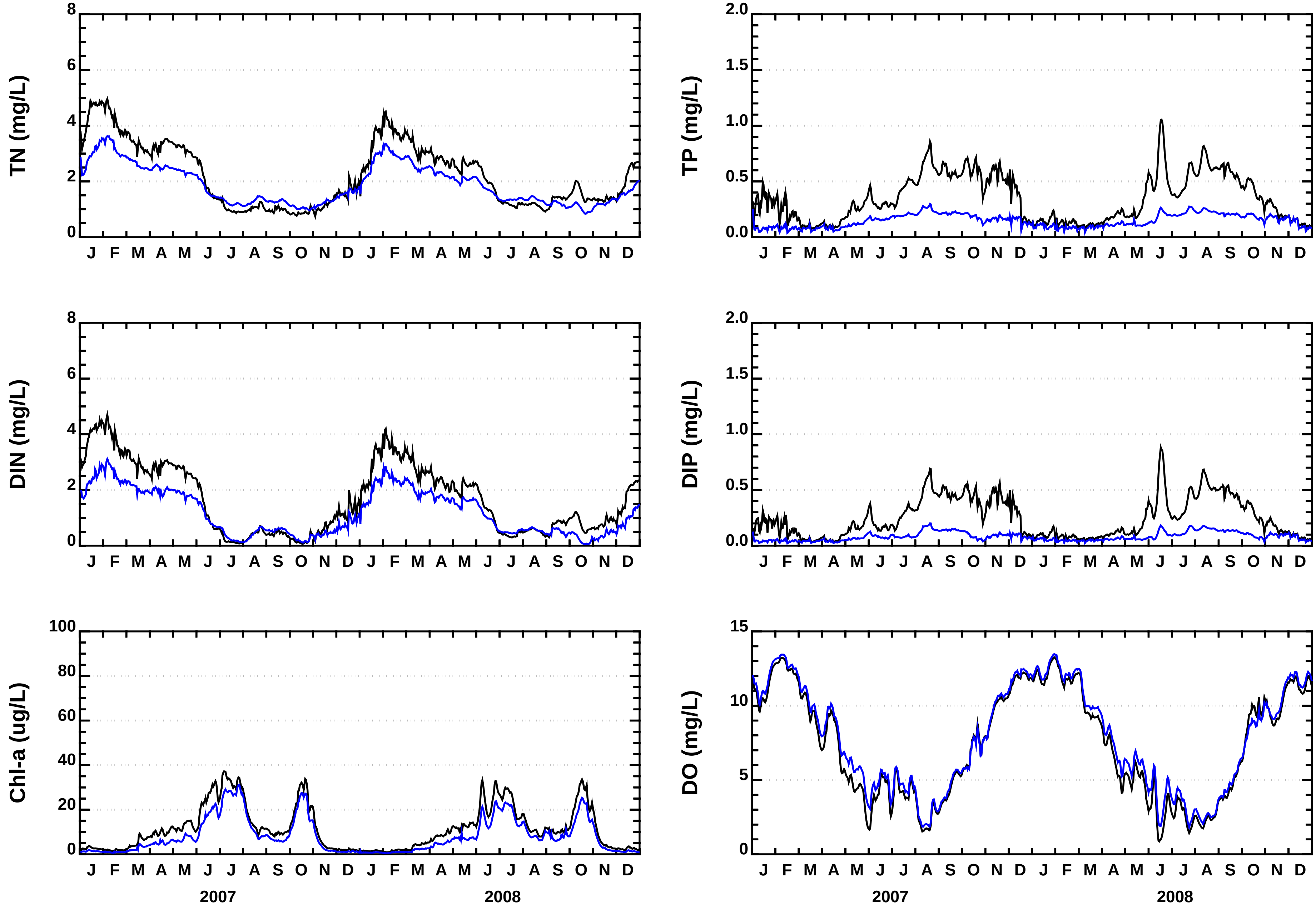


Figure 12. Murderkill River TMDL Loading Scenario Results Bay Road (Frederica) (206091)

(Black - Calibration, Blue - TMDL (F1) Scenario)

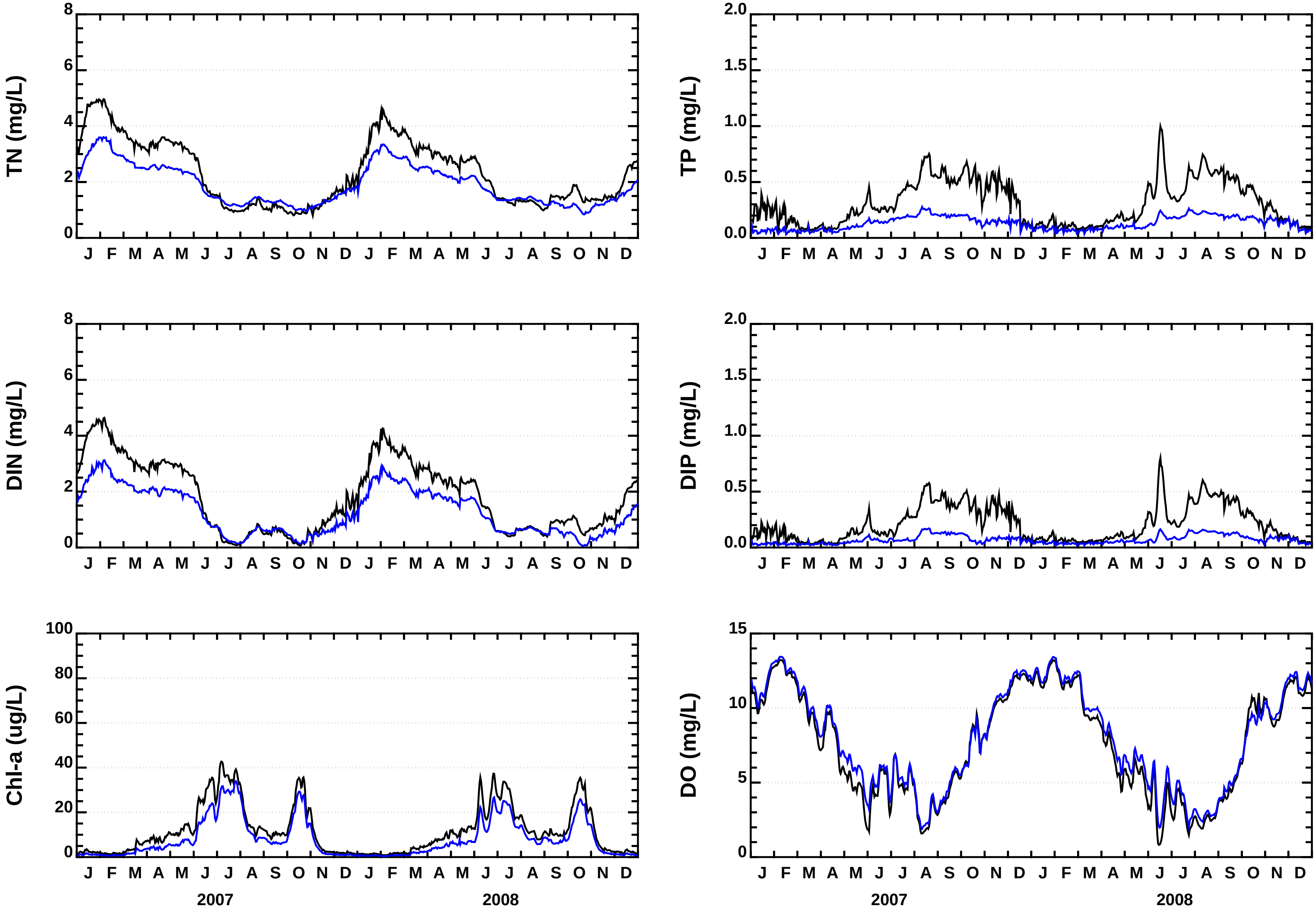


Figure 13. Murderkill River TMDL Loading Scenario Results Spring Creek at Rt. 12 Bridge at Frederica (206081)

(Black - Calibration, Blue - TMDL (F1) Scenario)

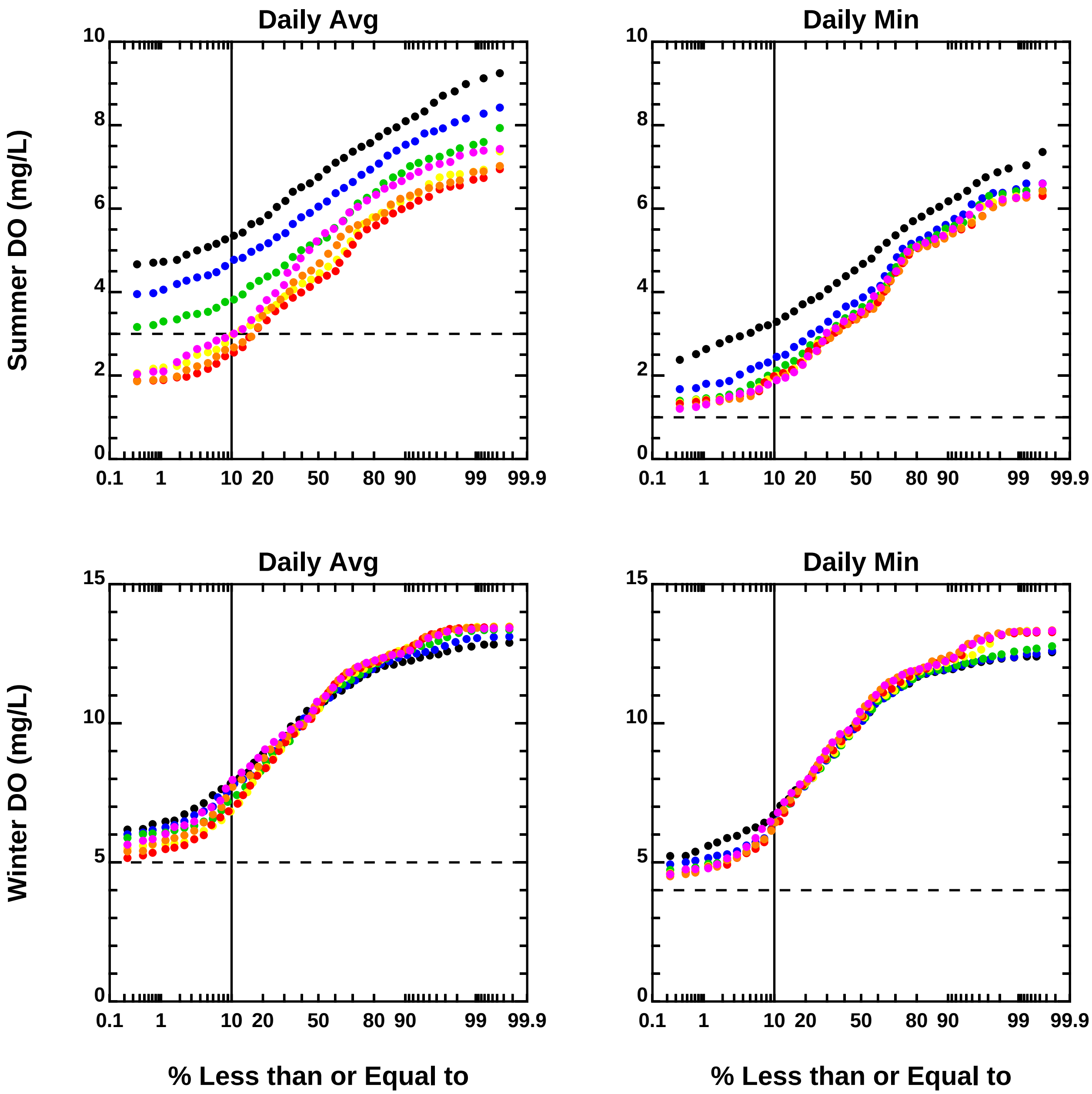


Figure 14. Murderkill River DO Probability Distributions for the TMDL Scenario
(Black - Zone 1, Blue - Zone 2, Green - Zone 3, Yellow - Zone 4, Red - Zone 5, Orange - Zone 6, Purple - Zone 7)

SECTION 6

PROPOSED TMDL LOAD REDUCTION

As stated, the proposed TMDL load reduction scenario is a 30% NPS reduction of nitrogen and 50% reduction of phosphorus in NPS watershed sources, as called for by the promulgated 2005 TMDL Regulation for the Murderkill River Watershed. These NPS load reductions are coupled with the revised point source Waste Load Allocations (WLA) and are presented in Tables 8 and 9 along with repair of failing septic systems. Figure 15 presents the location of the major sub-watersheds in the Murderkill River. In the tidal Murderkill River, the site-specific nutrient and DO criteria are attained at these TMDL loading levels.

Consideration that the loading conditions of the TMDL scenario results in attainment of all existing and proposed water quality standards, and the fact that NPS load reductions for this scenario are based on the 2005 promulgated TMDL, it was decided to amend only the WLA component of the 2005 TMDL. Table 10 presents the proposed WLA loadings for the Murderkill River watershed. These load reduction scenarios are meant as a guide in improving water quality in the Murderkill River watershed and should be periodically revisited to determine whether they are still applicable. In addition, water quality monitoring should continue throughout the watershed to quantify the instream effects of the proposed load reductions and to monitor the calculated water quality improvement in the river.

Table 8. Proposed Murderkill River WLA (Concentration)

Parameter	Harrington WWTP	KCRWTF
NPDES #	DE0020036	DE0020338
Effluent Type	Treated Municipal Wastewater	Treated Municipal Wastewater
Flow (MGD)	0.0	16.3
$CBOD_5$ (mg/L)	0.0	4.0
TN (mg/L)	0.0	6.6
NH_3 (mg/L)	0.0	0.13
NO_2+NO_3 (mg/L)	0.0	4.4
TP (mg/L)	0.0	0.375
PO_4 (mg/L)	0.0	0.176

Table 9. Proposed Murderkill River WLA (Loads)		
Parameter	**Harrington WWTP**	**KCRWTF**
NPDES #	DE0020036	DE0020338
Effluent Type	Treated Municipal Wastewater	Treated Municipal Wastewater
Flow (MGD)	0.0	16.3
$CBOD_5$ (lb/d)	0.0	544.0
TN (lb/d)	0.0	897.0
NH_3 (lb/d)	0.0	17.9
NO_2+NO_3 (lb/d)	0.0	601.0
TP (lb/d)	0.0	51.0
PO_4 (lb/d)	0.0	24.0

Table 10. Proposed Waste Load Allocation for the entire Murderkill River Watershed	
Parameter	**WLA (lb/d)**
TN	897.0 (annual average)
TP	51.0 (annual average)

6.1 CONSIDERATION OF THE IMPACT OF BACKGROUND POLLUTANTS

The Murderkill River watershed TMDLs for nutrients and DO were estimated using the results of calibrated/validated models (watershed, hydrodynamic and water quality). The models were developed using data collected in the field to represent model inputs and for calibration/validation of the models. The data collected in the field also reflected background pollutant conditions and Delaware Bay water quality in addition to tidal marsh loadings in the model. Therefore, the impact of background pollutants is accounted for in the model.

The impact of pollutant sources varies significantly according to location in the watershed. The major sources of nutrients are the watershed NPSs, the KCRWTF, the downstream boundary condition with Delaware Bay and the tidal marsh contribution of organic matter. The Delaware Bay impacts DO and nutrient levels closer to the mouth of the Murderkill River. Tidal marshes have an influence on DO and nutrient levels in the middle of the river as does the KCRWTF load. And the upstream watershed NPS loads affect DO and nutrient levels near the upstream reaches of the tidal river. These sources are the major causes of varying levels of background pollutants throughout the watershed and impact the model differently according to location.

6.2 CONSIDERATION OF CRITICAL ENVIRONMENTAL CONDITIONS

Low river flows during summer months coupled with high water temperatures represent critical conditions for point sources and also for nutrient related algal growth and DO impacts. High flow or wet weather conditions are also important for assessing nonpoint sources, which are present during the winter/spring season. The calibration/validation time period of 2007 and 2008 experienced annual total rainfalls amounts of 40.0 and 40.6 inches, respectively, which is below the average annual rainfall total of about 45 inches. Although the 2007-2008 modeling time period was below average, the watershed experienced a wide range of wet and dry flow conditions. Flow data were available at the following three freshwater USGS gages: Murderkill River near Felton (#01484000); Browns Branch near Harrington (#01484018); and Pratt Branch near Felton (#01484050). These gaged flows were extrapolated to the entire Murderkill River watershed area using a drainage area ratio and resulted in an average freshwater flow during the 2007-2008 modeling time period of 72 cfs (ranging from 14 to 940 cfs). The Murderkill River near Felton gage had historical records available for a number of periods (1931-1933, 1960-1985, 1996-1999, and 2007-2008). Based on these data a 7Q10 low flow of 1.7 cfs was calculated. During 2007 and 2008 the minimum 7-day average flow was 1.0 and 1.2 cfs, respectively. While the 2007-2008 modeling time period was representative of low-flow years there were periods of high flow and, therefore, the 2007-2008 time period represented a wide range of hydrologic conditions, and critical dry and wet weather conditions are included in the analysis.

6.3 CONSIDERATION OF SEASONAL VARIATIONS

Seasonal variations are considered in the Murderkill River models since the models were calibrated/validated in a time-variable mode for the years 2007-2008. This time period reflects flow and watershed conditions during all four seasons over a wide range of hydrologic conditions. Therefore, seasonal variations have been considered for this analysis.

6.4 CONSIDERATION OF MARGIN OF SAFETY

USEPAs technical guidance allows consideration for the margin of safety as implicit or explicit. The margin of safety can account for uncertainty about the relationships between pollutant loads and receiving water quality in addition to uncertainty in the analysis (USEPA, 2001). An implicit margin of safety is when conservative assumptions are contained in model development and TMDL establishment. An explicit margin of safety is a specified percentage of assimilative capacity that is kept unassigned to account for uncertainties, lack of sufficient data or future growth. An implicit margin of safety has been considered for the Murderkill River TMDL analysis.

The Murderkill River nutrient and DO models were constructed with several implicit, conservative assumptions built into the models. In addition, the models represented the complex watershed dynamics and tidal nature of the river as opposed to analyzing with a simple model framework not accounting for these complex processes that would include more uncertainty. As stated in the *Protocol for Developing Pathogen TMDLs* (USEPA, 2001), "trade-offs associated with using simpler approaches include a potential decrease in predictive accuracy and often an inability to predict water quality at fine geographic and time scales … and the advantages of more detailed approaches are presumably an increase in predictive accuracy and greater spatial and temporal resolution". The Murderkill River models were also developed from a comprehensive water quality database that was collected over several years (as described in this TMDL Modeling and Site-Specific Criteria Reports). This also reduces the uncertainty in the analysis based on a good understanding of water quality dynamics as determined from the available observed field data.

Furthermore for the TMDL scenarios, the reductions were applied to the entire watershed to satisfy the applicable water quality standards at the most critical location rather than to specific reaches upstream of the critical location (i.e., downstream impacts were considered). This results in an implicit margin of safety in upstream areas since load reductions are applied to meet the standards at the critical downstream locations. In the case of point sources, the WLAs were assigned as constant loads for the TMDL scenarios at the proposed effluent permit limits. Typical operating conditions at WWTPs are to not exceed permit limits and, therefore, discharge loadings are generally less than the effluent permit limits. Therefore, actual point source loadings will be less than the WLA used in the analysis. This will add an additional implicit margin of safety to this TMDL analysis.

It was also assumed that the load reductions required are to be achieved by solely altering practices within the Murderkill River watershed. In the nutrient model this means that the downstream Delaware Bay boundary condition loadings are not reduced due to upstream Delaware River controls in the States of Delaware, Pennsylvania, New York and New Jersey not to mention coastal water quality. Since there is intrusion of water from Delaware Bay into the river and water quality of Delaware Bay will undoubtedly improve in the future, this adds an additional level of conservatism to the analysis since the boundary conditions were not changed for the TMDL analysis.

Finally, critical stream conditions were considered in the TMDL analysis. That is, low-flow and high temperature conditions were part of the period that controlled the establishment of the TMDL loads. The nutrient loads, although based on annual average conditions, reflect the critical conditions that occur within this period. Particularly for point sources, the combination of low-flow, high temperature and permit loading conditions represent a rare occurrence and, therefore, provide an additional level of conservatism and implicit margin of safety. For nonpoint sources, critical conditions are more driven by high-flow runoff events and these conditions are also represented in this TMDL analysis.

Overall, the implicit margin of safety chosen reflects the complex modeling developed for the TMDL analysis, comprehensive database available for model development, conservative modeling assumptions chosen and the overall objective of DNREC to implement TMDLs in a phased, adaptive implementation strategy. The use of an implicit margin of safety allows water quality improvements to be realized within the adaptive management framework while not imposing unnecessary source reduction costs on local stakeholders until real world water quality improvements can be better correlated to economically feasible source controls.

6.5 CONSIDERATION OF MODEL CAPABILITIES AND LIMITATIONS

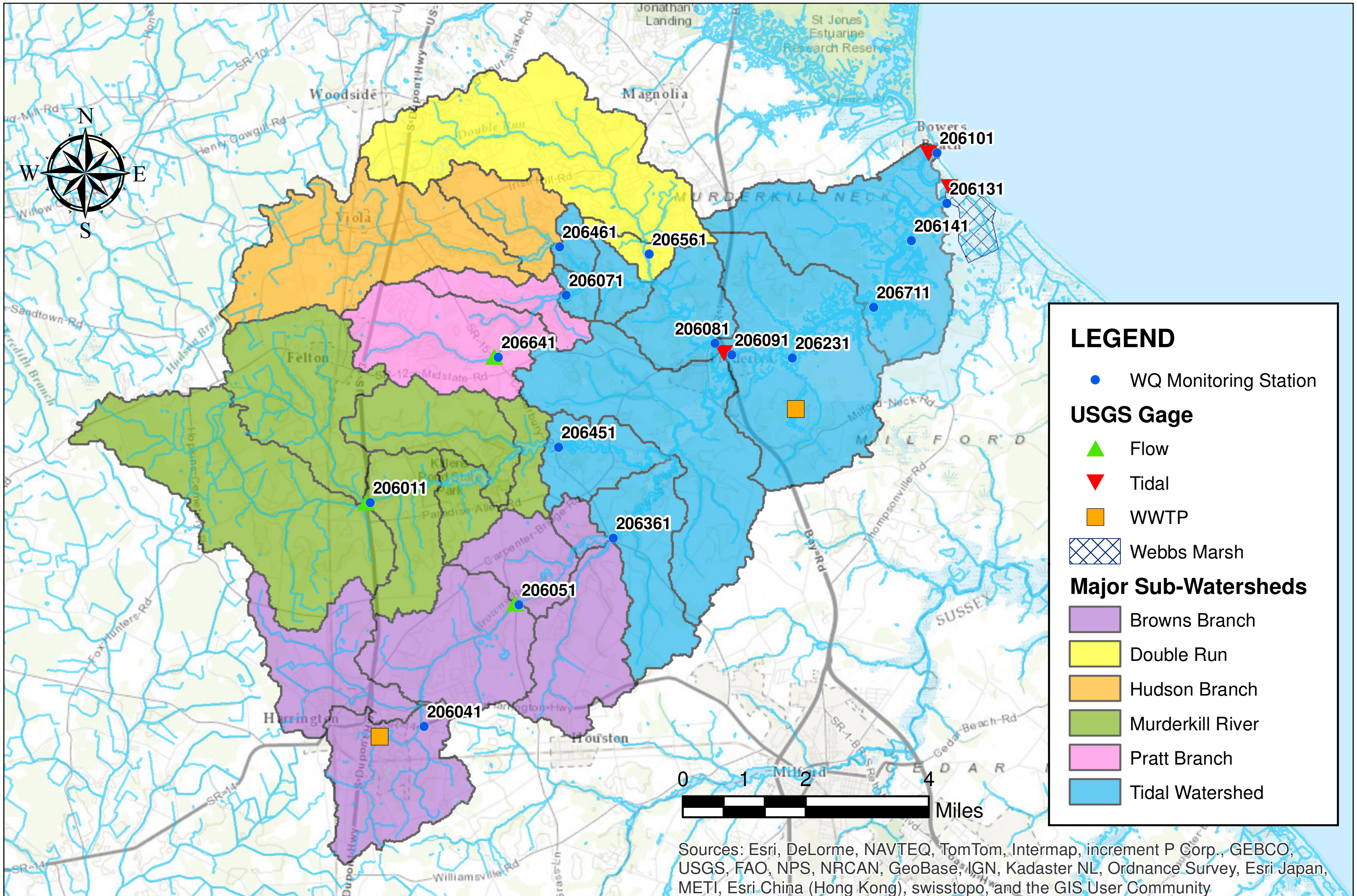
The Murderkill River watershed model is a valuable tool for the assessment and prediction of water quality parameters (including DO and nutrients) in the tidal and nontidal portions of the river. However, just like any model, the Murderkill River watershed model has limitations to go along with its capabilities. In the upstream nontidal reaches, the HSPF model has the ability to calculate instream concentrations at selected points in the river near water quality monitoring stations, lake inflows and outflows, confluences of reaches and other strategically selected locations. The driving functions for the model are the accumulation of pollutants on land uses and the delivery of pollutants to reaches through overland and groundwater flow. Moreover, HSPF is a lumped parameter and land use generalized model that is calibrated for whole watershed analyses and, therefore, HSPF's loading functions should not be used to assess the affects of a specific site on downstream water quality without further research and verification of accumulation rates and runoff concentrations at the site.

For the tidal reaches of the Murderkill River watershed, the coupled, three dimensional ECOMSED (hydrodynamic) and RCA (eutrophication, sediment flux) models account for the factors that influence water quality in a tidal system. Given the increased complexity of a tidal water body, the ECOMSED and RCA models are well suited to simulate flow and water quality because of their capabilities. It should be noted that the coupled model is loaded with flows and pollutant loads from the HSPF model and is, therefore, influenced by the same factors that limit HSPF. ECOMSED tracks flow and transport according to freshwater flow, density driven currents, wind driven currents and other meteorological influences and can calculate flow, velocity, salinity and temperature at any three dimensional point in the tidal water body.

The RCA eutrophication model can calculate DO, nutrients, carbon and chlorophyll-a concentrations at any three dimensional point in the water body based on sediment interactions, upstream sources of pollution, tidal flow and chemical interactions. The model also incorporates an annual average net flux of nutrients, and monthly average net flux of carbon and DO deficit from the tidal marshes. That is, nutrient, carbon and DO uptake and export from wetlands on a tidal basis was not considered in the marsh load but rather represented as an annual or monthly average net flux to or from the river. In general, the influence of nonpoint sources, point sources and boundary conditions from Delaware Bay on the water quality in the tidal water bodies of the Murderkill River can be assessed using the RCA eutrophication model.

6.6 TMDL IMPLEMENTATION / PUBLIC PARTICIPATION

This proposed amendment to the WLA component of the 2005 Murderkill River Watershed TMDL will be presented during a Public Hearing to be held on January 22, 2014 at the DNREC main office in Dover. All comments received before and during the Public Hearing process will be considered by DNREC. Based on the comments received, the report may be modified accordingly.



HDR | HydroQual

Figure 15. Major Subwatersheds in the Murderkill River

SECTION 7

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